Skyline Tension and Deflection HANDBOOK

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This paper is an expansion of "Skyline Logging Handbook on Wire Rope Tensions and Deflections," published in 1965.

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INTRODUCTION

This study of skyline tensions was prompted by the need for information on the capabilities of multispan skylines. As the study progressed, it was found that gaps existed in the information available on single-span skylines. It was also found, through parallel engineering studies on skyline logging, that single-span skylines were destined to find increased application. For that reason, it was decided to greatly supplement the information on single-span skylines so as to facilitate their efficient use and, similarly, to develop essential multispan skyline techniques.

Several researchers have investigated skyline cableways as used in the logging industry. Most previous applications required tedious and complex mathematical procedures. W. A. Davies[1/] presented one of the most usable studies to date by transforming the analytical work of R. Mills [2/] into tables and graphs which could be readily applied for solutions of single-span skyline problems. The loaded tension and deflection information in this study is an extension of Davies' work.

The mathematics of a catenary loaded at one point is treated fully by Mills (footnote 2) and is therefore omitted from this report. Unloaded catenaries are generally treated in most texts on analytical mechanics and are therefore also omitted.

The mathematics involved in deriving preload tensions in single-span skylines is an extension of basic knowledge on catenaries and stress/strain relationships of wire rope. The procedure shown for determining tensions in multispan skylines has no direct mathematical derivation since the equilibrium equations involved can only be solved by iteration.

GENERAL SKYLINE ENGINEERING

A rule to keep in mind, when planning a skyline, is that the capacity of a skyline to support a load generally increases with an increase in deflection, or sag of the line. A skyline with no deflection has no load-carrying ability. Actually, such a skyline cannot exist because its own weight causes some deflection.

[1/] Davies, William Albert. Development of graphical and tabular methods of determining tension in logging skylines. 28 pp., illus. 1946. (Unpublished graduate thesis on file at College of Forestry, University of Washington, Seattle.)

[2/] Mills, Russell. Tensions in logging skylines. Univ. Wash. Eng. Exp. Sta. Bull. 66, 30 pp., illus. 1932.

Skyline problems are approached in this report by first determining the skyline deflection that the terrain will allow and then finding the payload capability of the skyline at this deflection, using the tables or graphs in this report.

The problem of determining the allowable skyline deflection is best solved graphically. Tools needed are a drafting board, a length of chain, pins, a weight, and rectangular coordinate paper (large sheets or roll). It should be remembered that accuracy of graphical solutions gets better as the size of the layout is increased. A beaded chain, such as used on pull-type light sockets, or a fine-link chain is used to simulate the skyline catenary. For multispan problems, pins should be of sufficient diameter to allow the chain to feed freely between spans. Tacks, called push-pins, which have an elongated head, work well. The hook and weight, which simulate the carriage and payload, can be made from a paper clip and a rubber eraser.

Information about the terrain is needed to plot a profile of the skyline road. Important factors are the slope and the position of obstructions which will limit skyline deflection. Field notes, topographic maps, and stereophotographs are sources of profile data. A good approach to skyline planning is to perform preliminary design with the data available and then make a field check of the logging area to insure validity of the plan.

Figure 1 illustrates the important features of a single-span skyline or an intermediate span of a multispan skyline. This figure is also used to supplement the definitions of certain terms as used in this report which are listed below:

1. Support spar--spar tree, or mast, used to support skyline. The end supports are the headspar (at the landing) and the tailspar (at the other end of the skyline). Multispan skylines have additional intermediate supports which may be spars or cross cable supports.

2. Chord--a straight line between the skyline support points on the spars of a span.

3. Deflection--the vertical distance between the chord and the skyline. At the load, this is called the loaded deflection.

4. Clearance--the vertical distance below the skyline for the carriage, chokers, logs, and a desired ground clearance.

For a catenary loaded at one point, as is the case for a logging skyline, the maximum tension always occurs at the upper end of a sloping span. For a level skyline, the maximum tension occurs when the load is at midspan. On sloping skylines, the position of the load producing the maximum tension shifts slightly from the center in the direction of the lower end. However, for slopes up to 120 percent, the difference between the tension produced when the load is at the maximum tension position and that produced when the load is at midspan is negligible. Therefore, to simplify the mathematics, tension and deflection information presented in this report is based on a midspan load.

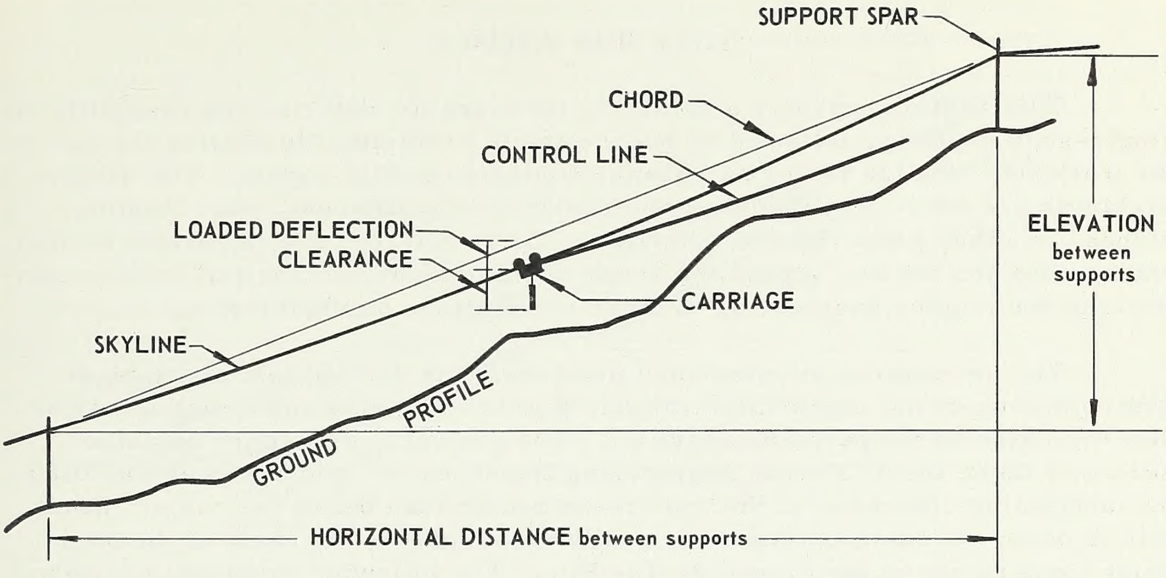

Figure 1.--Typical span of a logging skyline.

When the load is moving along a skyline, it is controlled by main and haulback lines or a snubbing line attached to the carriage. However, during log pickup, some carriages clamp to the skyline, whereas others are snubbed by a control line. The upper-end tension occurring when the load is clamped to the skyline is greater than that produced when the load is snubbed by a line, because the snubbing line supports the tangential component of the load. Procedures are given for obtaining tension due to the load when either a snubbing line or a carriage which clamps to the skyline is used. For the case of a clamping carriage, the analysis was performed with the assumption of a slack snubbing line. Skyline tension with a tight snubbing line cannot be presented in a general manner and is, therefore, not included.

The results contained in this report were determined by analyzing the mechanics of a skyline as a problem in statics, with no consideration given to the effect of load accelerations or impacts due to hangups. A minimum safety factor of 3 is recommended for skyline designs to account for these effects. The elastic limit of wire rope is approximately one-half of the breaking strength, which means that, if the rope is worked at a safety factor of approximately 2 or less, destructive stretch will occur.

SINGLE-SPAN SKYLINES

This section presents a detailed procedure for determining capability of single-span skylines, followed by some sample problems illustrating the use of the worksheet and the tables and graphs contained in this report. The sample problems are not to imply any recommendation of equipment, span lengths, slopes, or other properties of a skyline. These features are important to the engineering job but are beyond the scope of this report and are left to the experience of the logging engineer or to other publications on skylines.

The procedure, as mentioned previously, is divided into a graphical determination of the maximum allowable loaded deflection and a mathematical determination of the payload capability. The graphical procedure explained here was taken from "Forest Engineering Handbook" [3/] and has been modified by subtracting clearance at the spar trees rather than below the chain. When this is done, adequate clearance is available as long as the chain at the load point remains above the ground profile line. The following graphical procedure is shown on figure 2:

1. On rectangular coordinate paper attached to a drawing board, select a convenient scale (i. e., 1 inch = 100 feet) and draw profile of ground.
2. Select trial location for headspar and tailspar. Draw vertical lines to represent the spars. Estimate the height of skyline supports on each spar tree.
3. Determine minimum vertical clearance between skyline and ground for carriage, chokers, logs, and ground clearance. Subtract this clearance from the support height on the spar trees as shown in figure 2. Mark these points.
4. Draw a straight line (the chord) between these points and draw a vertical line at the midspan position.
5. Place a pin at each point marked on the spars and place a chain over the pins. Position the pins so that the chain crosses the spars at the marks. Figure 2 shows the method of stringing the chain. The upper end is secured on the pin at the upper spar, and the lower end is attached to a pin beyond the lower spar. This pin is secured in any position below the lower spar at this stage.
6. Place the drawing board in a vertical position, and hook the weight over the chain.

[3/] Pearce, J. Kenneth. Forest engineering handbook. U.S. Bur. Land Manage., Oreg. State Off., 220 pp., illus. 1961.

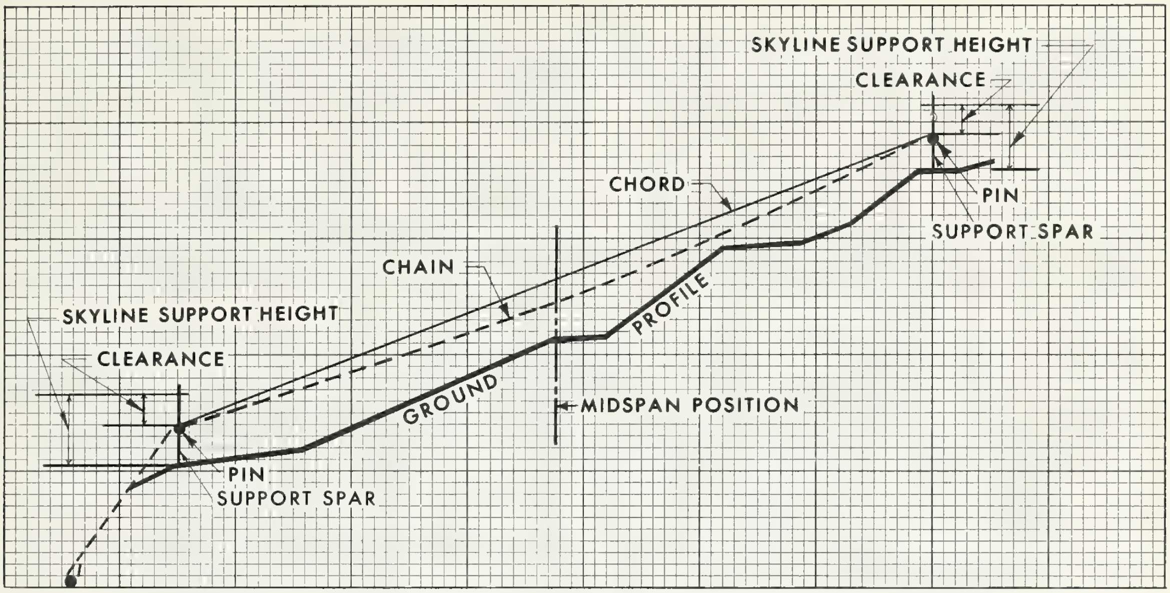

Figure 2.--Profile plot for determining allowable deflection.

7. Change the position of the pin at the lower end of the chain so that the chain at the weight just clears the ground profile.
8. Move the weight along the chain. Whenever the chain at the weight goes below the ground profile, adjust the lower pin so that the chain just clears the profile. Check entire span in this manner.
9. Move the weight to the midspan position and measure the vertical distance between the chain and the chord, which is the deflection. Obtain the percent allowable loaded deflection by dividing the deflection by the horizontal distance between supports and multiplying by 100.

The remainder of the problem consists of computing payload capability and unloaded tension. The computation is based on selecting a wire rope size and, with the allowable loaded deflection and the curves and tables contained in this report, performing a series of calculations which will result in the desired information. A worksheet (fig. 30) is provided to keep the following steps in their proper order:

1. From the skyline profile, determine:
   a. the allowable loaded deflection, which is the loaded deflection at midspan
   b. the horizontal span length
   c. the slope of the span.

2. Select a wire rope size and determine, from a wire rope catalog or table 1, the weight per foot of cable and the breaking strength.

3. Select a factor of safety. Determine the safe working load by dividing the breaking strength by the factor of safety.

4. Determine the carriage weight. The data included in these first three steps should be entered on the worksheet under "GIVEN."

5. Enter the safe working load in kips (1 kip = 1,000 pounds) on the worksheet.

6. Determine the upper-end tension due to cable weight. This is done by first consulting figure 11 or table 2. Figure 11 is a plot of some of the information in table 2, and the reader will find that a higher degree of accuracy can be obtained from table 2. The slope and deflection are used to determine the tension in kips per station [4/] per pound of cable weight per foot. This value is converted to tension in kips by multiplying by the number of stations and the cable weight per foot as indicated by the worksheet. This tension is subtracted from the safe working load to determine the remaining tension capability of the cable.

7. Gross load capability is determined by dividing the remaining tension capability by the tension in kips per kip of load. At this point, it is necessary to select which load condition is applicable--figure 12 (table 3) for tension due to load when the loaded carriage is unclamped and partially supported by a snubbing line or figure 13 (table 4) when the load is clamped to the skyline. The resulting gross load capability is reduced by the carriage weight to find the net payload capability or weight of logs that can be safely suspended.

If the payload determined at this point is not satisfactory, the whole procedure must be repeated. A larger diameter wire rope may support a heavier load but will also use up part of its additional capability in supporting its own weight. If an improved plow-steel rope was used in calculations leading to an insufficient payload capability, a trial with extra-improved,plow-steel rope will show that, for a particular size rope, the tension capability is increased about 15 percent. All of this increased capability goes to payload capability since the weight of the rope stays the same.

Changes in rope may still prove to yield an unsatisfactory payload and, if this is the case, changes in the profile must be made. The first logical step

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[4/] One station equals 100 feet.

is to see if more deflection is available by shortening the logs and/or chokers. If this fails, the only thing left to do is to shorten the span length by selecting new positions for the spar trees and proceed through the graphical and mathematical procedures again.

When a satisfactory payload capability has been found, the final step is to determine the tension required in the unloaded skyline to give the allowable loaded deflection at the maximum payload previously determined. This is done by completing the worksheet as outlined below:

1. Calculate the load factor by dividing the remaining cable tension capability in kips by the tension due to cable weight in kips per station and enter the allowable loaded deflection on the worksheet.
2. Determine the change in deflection due to removing the load by selecting one of the figures between figures 14 and 29. Each of these figures is for a specific loaded deflection. The figure is used by entering the horizontal axis at the load factor determined above, going up vertically to the proper span slope, and then going horizontally across to the change in deflection.
3. The unloaded deflection is then determined by subtracting the change from the loaded deflection.
4. Unloaded tension at the upper end is determined by entering figure 11 or table 2 with the slope of the span and unloaded deflection. The resulting tension in kips per station per pound of cable weight per foot is then multiplied by the number of stations and the weight of the cable per foot.

The unloaded tension curves (figs. 14 to 29) apply to wire rope with a modulus of elasticity of 14,000,000 p.s.i. Cables generally used for skyline logging have approximately this elastic modulus.

Values of unloaded tension and deflection are helpful in pretensioning the skyline where suitable instrumentation is available to obtain these readings. If the skyline is set up with more than the unloaded tension determined above, tensions occurring when the skyline is loaded to its designed capability will violate the safety factor and may result in cable failure. It is recommended that a suitable tension indicator be employed when setting up a skyline. If it is more convenient to make measurements at the lower end of the span, the lower-end unloaded tension can be determined by subtracting the cable weight per foot times the elevation between supports from the upper-end unloaded tension.

Table 5 presents the ratio of catenary length to the horizontal span length. Multiplying this ratio by the horizontal span length gives the length of the unloaded skyline. In estimating the length of wire rope required for the skyline, allowance must be made for the added lengths beyond the headspar and tailspar as well as any necessary wraps at the ends.

Single Span, Example Number 1

Problem

A logger has a quantity of 1-1/2-inch-diameter, extra-improved, plow-steel wire rope and a nonclamping carriage weighing 5,000 pounds. He wants to use this equipment on a skyline setting and has data to make a profile plot. The problem is to determine the payload capability of the skyline with a safety factor of 3.

Solution

A profile plot of the cableway is drawn, following the instructions in the text, from which the information below is obtained:

Horizontal distance between supports	3,000 feet
Elevation between supports	2,100 feet
Allowable midspan deflection	500 feet

A worksheet (fig. 3) is used to obtain a payload capability of 30,100 pounds and an unloaded tension of 23,200 pounds.

Unit No. ____

Skyline Road No. ____

DETERMINE FROM SKYLINE PROFILE:

Allowable loaded deflection — 16.7 percent

Horizontal span length (one station = 100 feet) — 30 stations

Slope of span — 70 percent

GIVEN:

Cable: Diameter 1 1/2 inches Weight 4.16 pounds/foot

Breaking strength 228 kips (1 kip = 1,000 pounds)

Factor of safety 3 Safe working load 76 kips

Skyline carriage weight 5 kips

DETERMINE REMAINING CABLE TENSION CAPABILITY:

Safe working load (given) — 76 kips

Subtract tension due to cable weight (fig. 11 or table 2):

0.164 kips/sta./lb./ft. x 30 stations x 4.16 lbs./ft. — - 20.5 kips

Remaining cable tension capability — 55.5 kips

DETERMINE GROSS LOAD CAPABILITY:

$$\frac{\text{Remaining tension capability } 55.5 \text{ kips}}{\text{Tension/kip of load* } 1.58 \text{ kips/kip}}$$ — 35.1 kips

Subtract carriage weight — - 5 kips

Payload capability — 30.1 kips

DETERMINE UNLOADED DEFLECTION:

Calculate load factor:

$$\frac{\text{Remaining cable tension capability } 55.5 \text{ kips}}{\text{Tension due to cable weight } 0.164 \text{ kips/sta./lb./ft.} \times 4.16 \text{ lb./ft.}}$$ — 81

Allowable loaded deflection — 16.7 percent

Subtract deflection change with load removed (figs. 14 to 29) — - 3.1 percent

Unloaded deflection — 13.6 percent

DETERMINE UNLOADED TENSION USING UNLOADED DEFLECTION (fig. 11 or table 2):

0.186 kips/sta./lb./ft. x 30 stations x 4.16 pounds/foot — 23.2 kips

*Use figure 12 or table 3 when load is not clamped and is partially supported by a snubbing line. Use figure 13 or table 4 when the load is clamped to the skyline.

Figure 3.--Single-span skyline worksheet (example 1).

Single Span, Example Number 2

Problem

A profile plot of a skyline road yields the following information:

Horizontal distance between supports	2,500 feet
Elevation between supports	1,570 feet
Allowable midspan deflection	200 feet

The problem is to determine what size extra-improved, plow-steel wire rope is required for a payload of 9,000 pounds. A nonclamping carriage weighing 700 pounds is to be used. The safety factor is 3.

Solution

The first trial is performed, assuming a 1-inch-diameter wire rope, which results in a payload of 5,900 pounds. Next, a 1-1/2-inch-diameter wire rope is tried, which results in a payload of 13,600 pounds. A plot of payload versus diameter is made with a straight line between the two points obtained from the first two trials above. (The straight line is an approximation of the actual curve of payload versus diameter but is fairly close in most cases and reduces the number of trials required in this type of problem.) This plot indicates that 1-1/4-inch-diameter cable should provide the desired payload. Figure 4 shows the computations on a worksheet for this problem with a 1-1/4-inch cable, which results in a payload of 9,400 pounds.

MULTISPAN SKYLINES

Figure 5 illustrates the important features of a multispan skyline. The method for determining the capability of multispan skylines is quite similar to that used for single spans and allows use of the same procedures. As in single spans, the procedure consists of a graphical determination of allowable deflection followed by a mathematical determination of payload capability. The multispan problem is more difficult, because a payload determined from one span may produce a higher maximum cable tension when it is in some other span. This phenomenon has no direct mathematical solution, and a precise answer would require a tedious iterative process for each multispan configuration. An approximate method for determining the capability of all spans in a multispan skyline has been devised which will give reasonably accurate results if performed carefully. The use of this approximate method is recommended, as the logging engineer could not justify the time and cost required to obtain a precise solution for each skyline. Before we get into the details of the procedure for multispans, the problem and method of solution will be discussed.

Unit No. ____

Skyline Road No. ____

DETERMINE FROM SKYLINE PROFILE:

Allowable loaded deflection — 8 percent

Horizontal span length (one station = 100 feet) — 25 stations

Slope of span — 63 percent

GIVEN:

Cable: Diameter 1 1/4 inches Weight 2.89 pounds/foot

Breaking strength 159.8 kips (1 kip = 1,000 pounds)

Factor of safety 3 Safe working load 53.3 kips

Skyline carriage weight 0.7 kips

DETERMINE REMAINING CABLE TENSION CAPABILITY:

Safe working load (given) — 53.3 kips

Subtract tension due to cable weight (fig. 11 or table 2):

0.258 kips/sta./lb./ft. x 25 stations x 2.89 lbs./ft. — - 18.6 kips

Remaining cable tension capability — 34.7 kips

DETERMINE GROSS LOAD CAPABILITY:

$$\frac{\text{Remaining tension capability } 34.7 \text{ kips}}{\text{Tension/kip of load* } 3.44 \text{ kips/kip}} = 10.1 \text{ kips}$$

Subtract carriage weight — - 0.7 kips

Payload capability — 9.4 kips

DETERMINE UNLOADED DEFLECTION:

Calculate load factor:

$$\frac{\text{Remaining cable tension capability } 34.7 \text{ kips}}{\text{Tension due to cable weight } 0.258 \text{ kips/sta./lb./ft.} \times 2.89 \text{ lb./ft.}} = 47$$

Allowable loaded deflection — 8 percent

Subtract deflection change with load removed (figs. 14 to 29) — - 2.8 percent

Unloaded deflection — 5.2 percent

DETERMINE UNLOADED TENSION USING UNLOADED DEFLECTION (fig. 11 or table 2):

0.373 kips/sta./lb./ft. x 25 stations x 2.89 pounds/foot — 26.9 kips

*Use figure 12 or table 3 when load is not clamped and is partially supported by a snubbing line. Use figure 13 or table 4 when the load is clamped to the skyline.

Figure 4.--Single-span skyline worksheet (example 2).

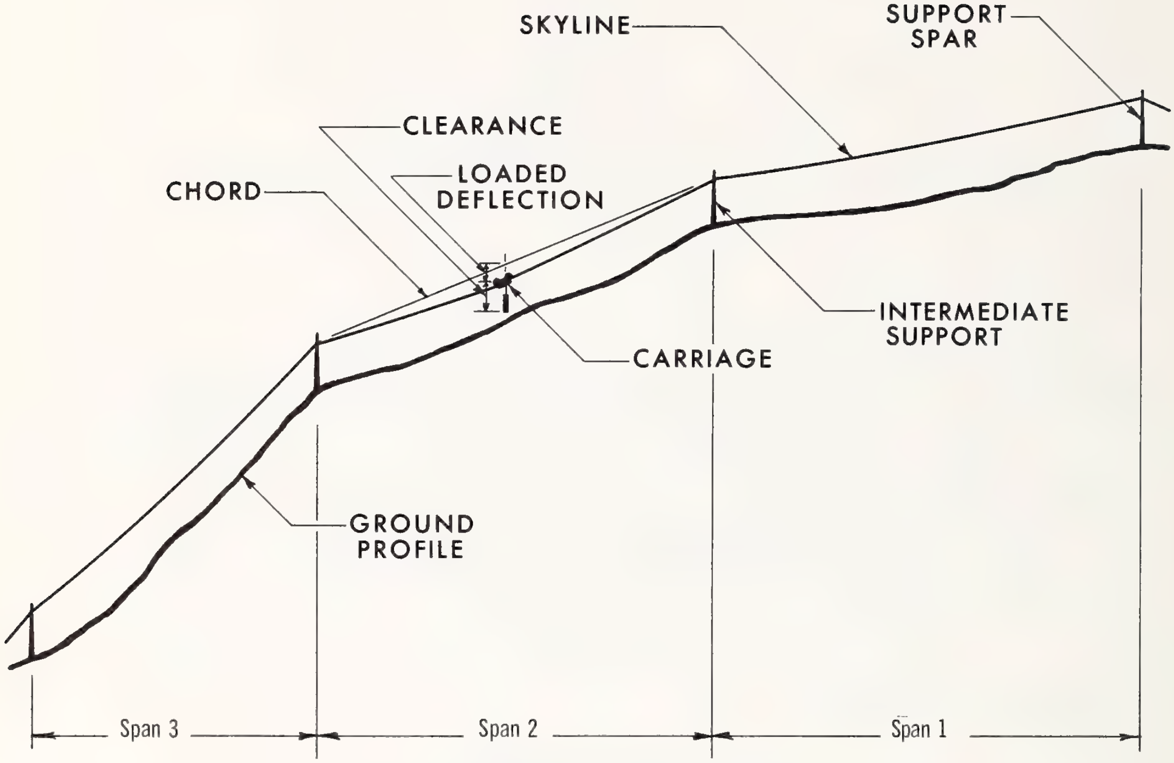

Figure 5.--Typical multispan logging skyline.

The general approach to the problem is one which considers the loaded multispan skyline. At any time, the load will be in only one span, and the line will have a certain loaded deflection and tension. When only this span is considered, it does not matter whether it is a single span or part of a multispan from the support trees inward. The tensions produced at the ends of this span are the same as those produced in a single span with the same load, slope, wire rope size, and deflection. However, the tension at the upper end of this span is not the maximum tension in the multispan unless it is the top span. To obtain the maximum tension in a multispan with a load in one of the lower spans, use is made of the mathematical property of a catenary that the difference in tension between any two points along the catenary is equal to the difference in height of the points multiplied by the unit weight of the cable. This means that the difference in tension at the ends of an unloaded span is equal to the difference in elevation of the supports in feet times the weight per foot of cable. From this, it follows that the difference in tension from the top of a loaded span to the top of a multispan is the difference in elevation times the unit cable weight, regardless of the number of spans between. Similarly, the tension decreases from the lower end of a loaded span to the lowest point on the skyline; but, since we are looking for the effect of the maximum tension, we need only be concerned with the loaded span and the spans above the loaded span.

When a span of a multispan is considered in this way, the payload of this span can be determined by, first, finding the allowable deflection in the span graphically and, then, using the tables and graphs to determine the payload capability based on a cable working load in exactly the same way as a single-span problem. However, when this payload is moved to the center of another span in the multispan, it is possible that the cable working load will be exceeded. The problem is handled by adjusting the chain length and the weight used in the graphical analysis so that the chain closely approximates the loaded skyline cable. This allows transfer of the weight to various spans to determine their respective payload capabilities. The smallest payload determined in this manner is the payload capability of the entire multispan.

The graphical part of the procedure for establishing the payload capability of a multispan is illustrated in figure 6 and consists of the following steps:

1. On rectangular coordinate paper attached to a drawing board select a convenient scale and draw a profile of the ground.

2. Select trial location for support spars and estimate height of skyline supports above ground.

3. Determine minimum vertical clearance between skyline and ground for carriage, chokers, logs, and ground clearance. Subtract this clearance from the support height on the spar trees as shown in figure 6. Mark these points.

4. Draw straight lines (chords) between points on adjacent spars. Also draw a vertical line at the midspan positions and number the spans starting with the top span.

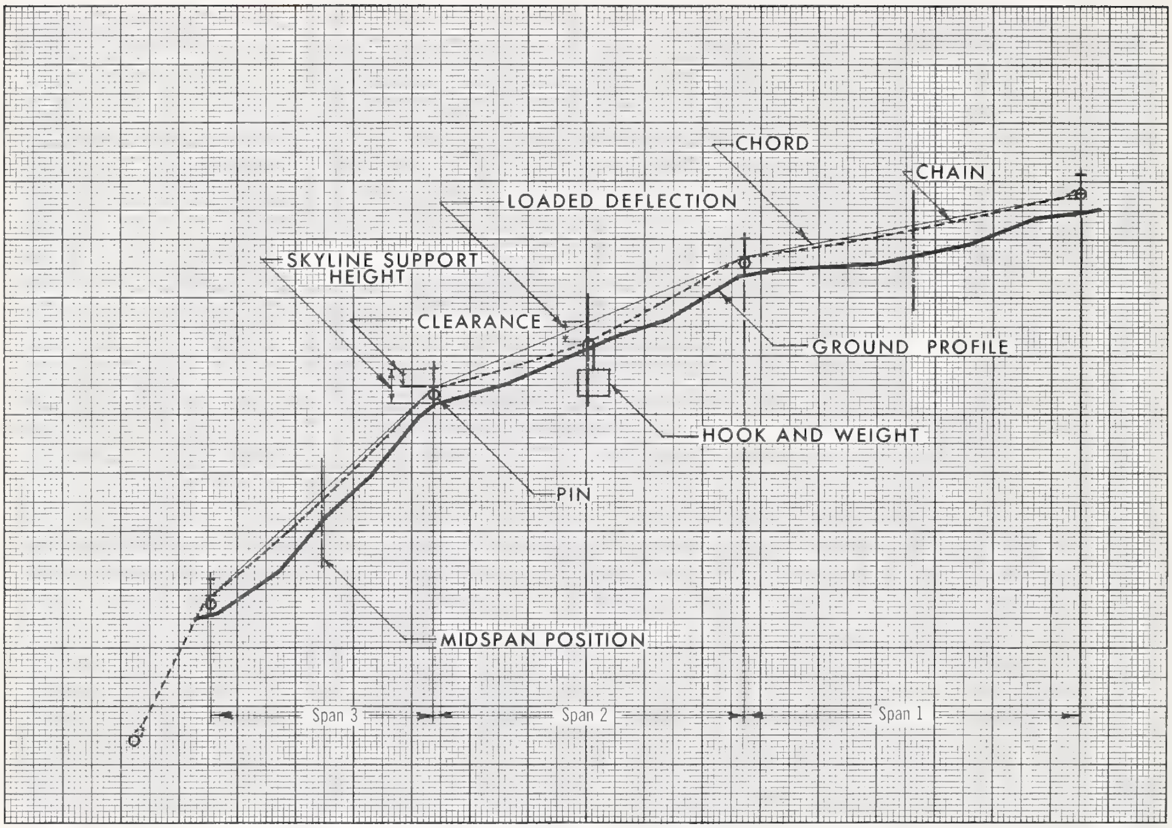

Figure 6.

Figure 6.--Multispan profile plot for determining allowable deflection.

5. Place a pin at each point marked on the spars and string a chain over the pins. The upper end is secured to the upper spar pin and the lower end is attached to a pin beyond the lower spar. This pin is secured in any position below the lower spar at this stage. Adjust the pins so that the chain crosses the spars at the marks.

6. Place the drawing board in a vertical position and hook a small weight over the chain.

7. Change the position of the pin at the lower end of the chain so that the chain at the weight just clears the ground profile.

8. Move the weight along the chain. Whenever the chain at the weight goes below the ground profile, adjust the lower pin so that the chain just clears the profile. Check all spans in this manner.

9. Place the weight at the center of span number 2 (the span next to the upper span). Examine the deflection in the upper span and obtain the percent deflection (vertical midspan deflection divided by horizontal span length).

10. Obtain the percent deflection that the upper span should contain based on the working load of the wire rope from either figure 7 or the relationship:

$$(T)(S)(W) = \frac{B.S.}{S.F.}$$

where: T = upper end tension (kips/sta/lb/ft)
S = horizontal span length in stations (1 station = 100 feet)
W = cable weight (lb/ft)
B.S. = breaking strength of wire rope (kips)
S.F. = safety factor

Solve for T and consult figure 11 or table 2 for percent deflection.

Figure 7 is based on a 1-1/2-inch-diameter, extra-improved, plow-steel wire rope worked to a safety factor of 3. There is a minor deviation from the values shown for other rope sizes, but the deviation is within the accuracy of the graphical solution.

11. If the percent deflection in the upper span of the graphical analysis is different from what it should be, the weight must be adjusted. To obtain more deflection in the upper span, remove some weight or, to obtain less deflection, add some weight. If the amount of weight is changed, it is necessary to readjust the chain (steps 7 and 8) and then recheck the upper-span deflection (steps 9, 10, and 11).

12. Place the weight in the center of each span and obtain the percent deflection (vertical midspan deflection divided by horizontal span length). Also obtain the slope, horizontal span length, and elevation between top of span and top of skyline.

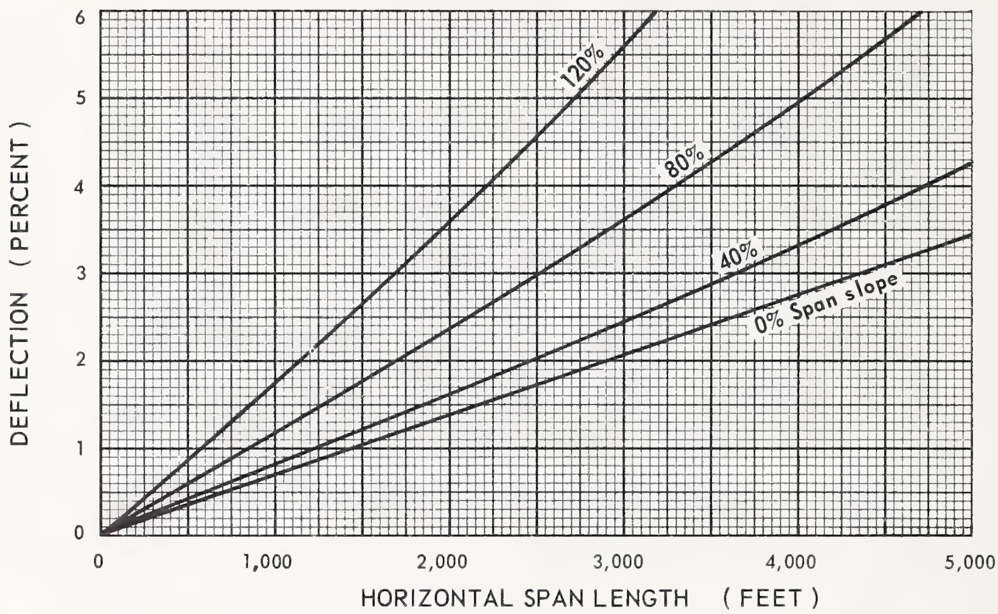

Figure 7.--Deflection vs. span length for various span slopes (unloaded catenary with 1-1/2-inch-diameter, extra-improved, plow-steel wire rope stressed to one-third breaking strength).

This concludes the graphical phase of the analysis. The rest of the problem is performed with the aid of the multispan worksheet (fig. 31). A separate worksheet is required for each span. The steps for each span are as follows:

1. Enter the following information from the profile plot:
   a. the span number
   b. the loaded midspan deflection
   c. the horizontal span length
   d. the slope of the span
   e. the vertical distance from the top of the span to the top of the skyline.
2. Select a wire rope size and determine, from a wire rope catalog or table 1, the weight per foot of cable and the breaking strength.
3. Select a factor of safety and determine the safe working load by dividing the breaking strength by the factor of safety.

4. Enter the carriage weight on the worksheet. (Steps 2, 3, and 4 are the same for all worksheets.)

5. Enter the safe working load on the worksheet.

6. Determine the tension capability loss from the top of the skyline to the top of the span in question by multiplying the vertical distance from top of span to top of skyline by the unit cable weight and subtract this from the safe working load.

7. Use figure 11 or table 2 to obtain the tension due to cable weight in kips per station per pound per foot; then multiply this by the number of stations and the unit cable weight. Subtract this tension from the safe working load to determine the remaining tension capability.

8. Next, calculate the gross load capability of the line by dividing the remaining tension capability by the tension per kip of load obtained from figure 12 or table 3 when the load is not clamped and is partially supported by a snubbing line, or from figure 13 or table 4 when the load is clamped to the skyline.

9. Subtract the carriage weight from the gross load capability to obtain the payload capability for this span.

Capability of each span is determined in this way, and the minimum capability is the capacity of the multispan. If the payload capability is insufficient, increase the deflections by reducing the clearance (if possible), use a larger rope size, or change the number and/or locations of the support trees. An excessive payload capability suggests that a smaller rope can be used or, possibly, that some intermediate supports can be deleted.

Obtaining the unloaded tension to properly set up a multispan skyline is tedious and complex, involving a consideration of the equilibrium transition from the loaded to the unloaded condition. The influence of cable elasticity as well as feed-over between spans requires an iterative solution for each configuration. Since no convenient way has been found to present data applicable to general situations, the experience and judgment of the logging engineer must be employed in the solution of this problem. Probably the most reasonable approach to obtaining the required unloaded tension is to attach the capacity payload to the carriage in the critical span and then tighten the line until the tension reaches the working load. When the load is removed, the cable is at the proper unloaded tension. This method requires use of a tension indicator.

Multispan, Example Number 1

Problem

It is desired to rig a 1-5/8-inch-diameter skyline on a convex slope. The overall horizontal yarding distance is 2,660 feet, and the vertical difference in elevation is 1,420 feet.

Solution

A profile plot of the slope is drawn, and the plot indicates that three spans will be required. After stringing the chain and adjusting the weight according to the directions in the text, the following dimensions are determined from the plot:

Span 1 (upper span)

Horizontal span length	1,050 feet
Elevation between supports	200 feet
Loaded-midspan deflection	57 feet

Span 2 (intermediate span)

Horizontal span length	840 feet
Elevation between supports	470 feet
Loaded-midspan deflection	60 feet

Span 3 (lower span)

Horizontal span length	770 feet
Elevation between supports	750 feet
Loaded-midspan deflection	77 feet

A safety factor of 3 is applied to the extra-improved, plow-steel wire rope, and a nonclamping carriage weighing 3,000 pounds is to be used.

This information and three multispan worksheets (see figs. 8, 9, and 10) are used in calculating the capability of each span. The three spans are found to have capabilities of 13.2, 17.1, and 20.3 kips, which limits this skyline to a payload of 13.2 kips.

Unit No. ____

Skyline Road No. ____

DETERMINE FROM SKYLINE PROFILE:

Span location	Span No. 1
Loaded-midspan deflection	5.4 percent
Horizontal span length (one station = 100 feet)	10.5 stations
Slope of span	19 percent
Vertical distance from top of span to top of skyline	- feet

GIVEN:

Cable: Diameter 1 5/8 inches Weight 4.88 pounds/foot

Breaking strength 264 kips (1 kip = 1,000 pounds)

Factor of safety 3 Safe working load 88 kips

Skyline carriage weight 3 kips

DETERMINE REMAINING CABLE TENSION CAPABILITY:

Safe working load (given)	88 kips
Subtract tension between span and top of skyline:	
Vertical distance ____ ft. x ____ lbs./ft./1,000	- - kips
Safe working load at top of span	88 kips
Subtract tension due to cable weight (fig. 11 or table 2):	
0.255 kips/sta./lb./ft. x 10.5 stations x 4.88 lb./ft.	- 13.1 kips
Remaining cable tension capability	74.9 kips

DETERMINE GROSS LOAD CAPABILITY:

$\dfrac{\text{Remaining tension capability } 74.9 \text{ kips}}{\text{Tension/kip of load* } 4.62 \text{ kips/kip}}$	16.2 kips
Subtract carriage weight	- 3 kips
Payload capability of span	13.2 kips

*Use figure 12 or table 3 when load is not clamped and is partially supported by snubbing line. Use figure 13 or table 4 when load is clamped to skyline.

Figure 8.--Multispan skyline worksheet (example 1, span 1).

Unit No. _____

Skyline Road No. _____

DETERMINE FROM SKYLINE PROFILE:

Span location	Span No. 2
Loaded-midspan deflection	7.1 percent
Horizontal span length (one station = 100 feet)	8.4 stations
Slope of span	56 percent
Vertical distance from top of span to top of skyline	200 feet

GIVEN:

Cable: Diameter 1 5/8 inches Weight 4.88 pounds/foot

Breaking strength 264 kips (1 kip = 1,000 pounds)

Factor of safety 3 Safe working load 88 kips

Skyline carriage weight 3 kips

DETERMINE REMAINING CABLE TENSION CAPABILITY:

Safe working load (given)	88 kips
Subtract tension between span and top of skyline:	
Vertical distance 200 ft. x 4.88 lbs./ft./1,000	- 1.0 kips
Safe working load at top of span	87.0 kips
Subtract tension due to cable weight (fig. 11 or table 2):	
0.266 kips/sta./lb./ft. x 8.4 stations x 4.88 lb./ft.	- 10.9 kips
Remaining cable tension capability	76.1 kips

DETERMINE GROSS LOAD CAPABILITY:

$\frac{\text{Remaining tension capability } 76.1 \text{ kips}}{\text{Tension/kip of load* } 3.79 \text{ kips/kip}}$	20.1 kips
Subtract carriage weight	- 3 kips
Payload capability of span	17.1 kips

*Use figure 12 or table 3 when load is not clamped and is partially supported by snubbing line. Use figure 13 or table 4 when load is clamped to skyline.

Figure 9.--Multispan skyline worksheet (example 1, span 2).

Unit No. ____

Skyline Road No. ____

DETERMINE FROM SKYLINE PROFILE:

Span location — Span No. 3

Loaded-midspan deflection — 10 percent

Horizontal span length (one station = 100 feet) — 7.7 stations

Slope of span — 97 percent

Vertical distance from top of span to top of skyline — 670 feet

GIVEN:

Cable: Diameter 1 5/8 inches   Weight 4.88 pounds/foot

Breaking strength 264 kips (1 kip = 1,000 pounds)

Factor of safety 3   Safe working load 88 kips

Skyline carriage weight 3 kips

DETERMINE REMAINING CABLE TENSION CAPABILITY:

Safe working load (given) — 88 kips

Subtract tension between span and top of skyline:

Vertical distance 670 ft. x 4.88 lbs./ft./1,000 — - 3.3 kips

Safe working load at top of span — 84.7 kips

Subtract tension due to cable weight (fig. 11 or table 2):

0.302 kips/sta./lb./ft. x 7.7 stations x 4.88 lb./ft. — - 11.3 kips

Remaining cable tension capability — 73.4 kips

DETERMINE GROSS LOAD CAPABILITY:

Remaining tension capability 73.4 kips / Tension/kip of load* 3.15 kips/kip — 23.3 kips

Subtract carriage weight — - 3 kips

Payload capability of span — 20.3 kips

*Use figure 12 or table 3 when load is not clamped and is partially supported by snubbing line. Use figure 13 or table 4 when load is clamped to skyline.

Figure 10.--Multispan skyline worksheet (example 1, span 3).

Multispan, Example Number 2

Problem

A skyline road has a profile containing roughly 3,000 feet at a slope of 30 percent at the upper end followed by 1,400 feet at a slope of 65 percent at the lower end. A 1-1/4-inch-diameter, extra-improved, plow-steel wire rope at a safety factor of 3 is to be used in conjunction with a 1,200-pound carriage which clamps to the skyline. A payload capability of 9,000 pounds is necessary for this setting.

Solution

The profile is laid out and a trial is made with three spans. The chain is strung, the weight is adjusted, and the following dimensions are obtained:

Span 1 (upper span)

Horizontal span length	1,470 feet
Elevation between supports	380 feet
Loaded-midspan deflection	80 feet

Span 2 (intermediate span)

Horizontal span length	1,530 feet
Elevation between supports	510 feet
Loaded-midspan deflection	90 feet

Span 3 (lower span)

Horizontal span length	1,400 feet
Elevation between supports	910 feet
Loaded-midspan deflection	100 feet

Three worksheets are used to determine the payload capabilities of these spans which are 7.3, 7.5, and 7.5 kips, respectively (the computations are left as an exercise for the reader). This gives a capability of 7.3 kips for the skyline.

Since this is below the desired capability, a trial with four spans is next attempted. The positions of the supports on the profile plot are changed and the chain and weight are adjusted, resulting in the following:

Span 1

Horizontal span length	940 feet
Elevation between supports	280 feet
Loaded-midspan deflection	80 feet

Span 2

Horizontal span length	870 feet
Elevation between supports	220 feet
Loaded-midspan deflection	65 feet

Span 3

Horizontal span length	1,300 feet
Elevation between supports	450 feet
Loaded-midspan deflection	100 feet

Span 4

Horizontal span length	1,290 feet
Elevation between supports	850 feet
Loaded-midspan deflection	110 feet

Proceeding through four worksheets (again left as an exercise) results in span capabilities of 13.7, 12.0, 10.9, and 9.6 kips, respectively, which results in an overall capability of 9.6 kips.

APPENDIX

Table 1.--Typical skyline wire rope specifications

(6x19, 6x21, or 6x25 IWRC[1/])

Cable dimensions		Improved plow steel		Extra-improved plow steel	
Diameter (inches)	Weight per foot (pounds)	Safe working load[2/]	Breaking strength	Safe working load[2/]	Breaking strength
		Kips	Kips	Kips	Kips
1/4	0.116	1.96	5.88	2.27	6.80
5/16	.18	3.05	9.16	3.51	10.54
3/8	.26	4.37	13.12	5.0	15.1
7/16	.35	5.93	17.78	6.8	20.4
1/2	.46	7.7	23.0	8.9	26.6
9/16	.59	9.7	29.0	11.2	33.6
5/8	.72	12.0	36.0	13.7	41.2
3/4	1.04	17.1	51.2	19.6	58.8
7/8	1.42	23.1	69.2	26.5	79.6
1	1.85	30.0	90.0	34.5	103.4
1-1/8	2.34	37.7	113.2	43.3	130.0
1-1/4	2.89	43.3	130.0	53.3	159.8
1-3/8	3.50	55.7	167.0	64.0	192.0
1-1/2	4.16	65.9	197.8	76.0	228.0
1-5/8	4.88	76.7	230.0	88.0	264.0
1-3/4	5.67	89.3	268.0	102.0	306.0
1-7/8	6.50	101.3	304.0	116.0	348.0
2	7.39	114.7	344.0	132.0	396.0
2-1/8	8.35	128.7	386.0	147.3	442.0
2-1/4	9.36	143.3	430.0	164.7	494.0
2-1/2	11.6	175.3	526.0	201.3	604.0
2-3/4	14.0	209.3	628.0	240.7	722.0

1/ Independent wire rope core.

2/ Based on a safety factor of 3.

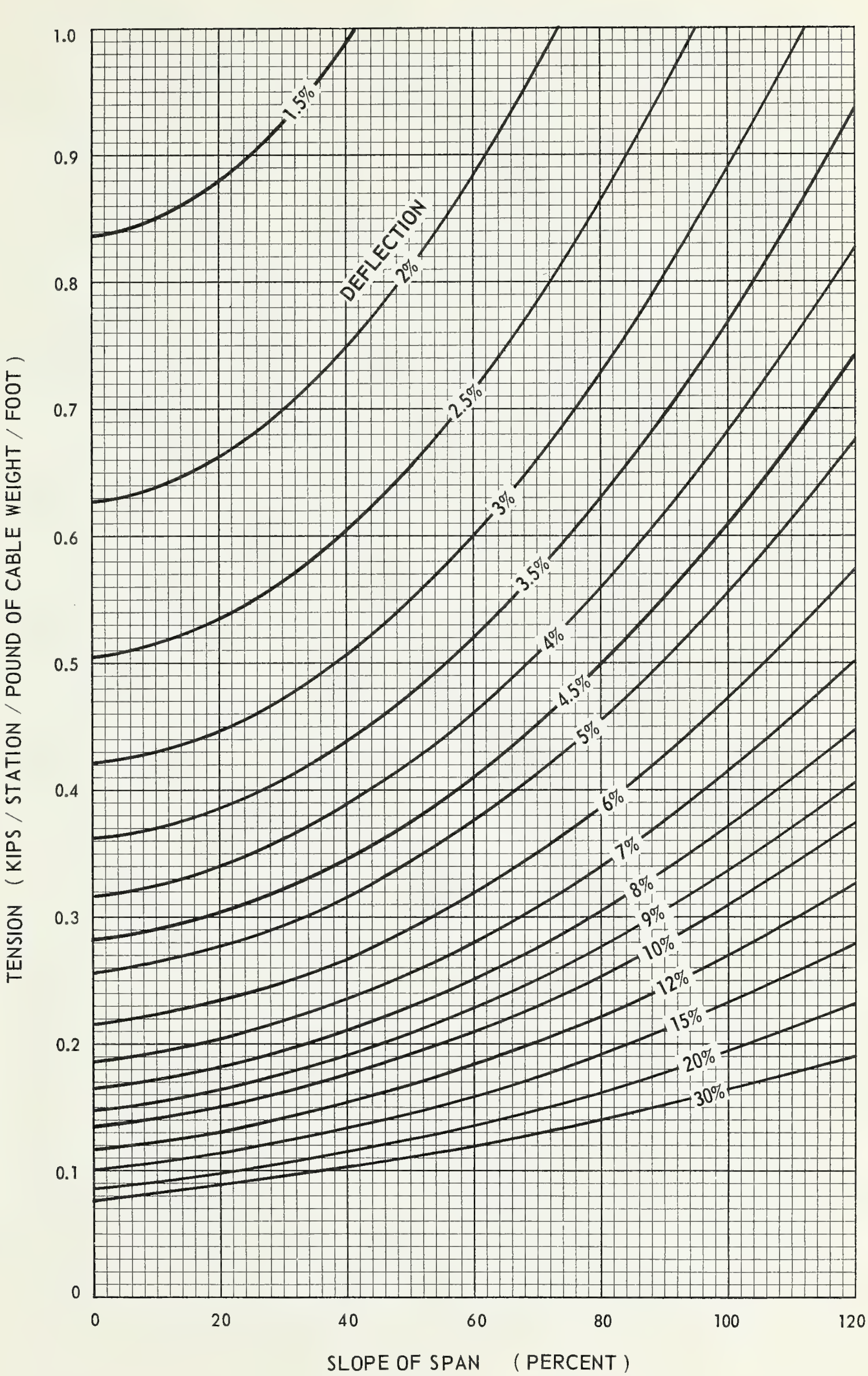

Figure 11.--Upper-end tension due to cable weight vs. slope of span for various deflections.

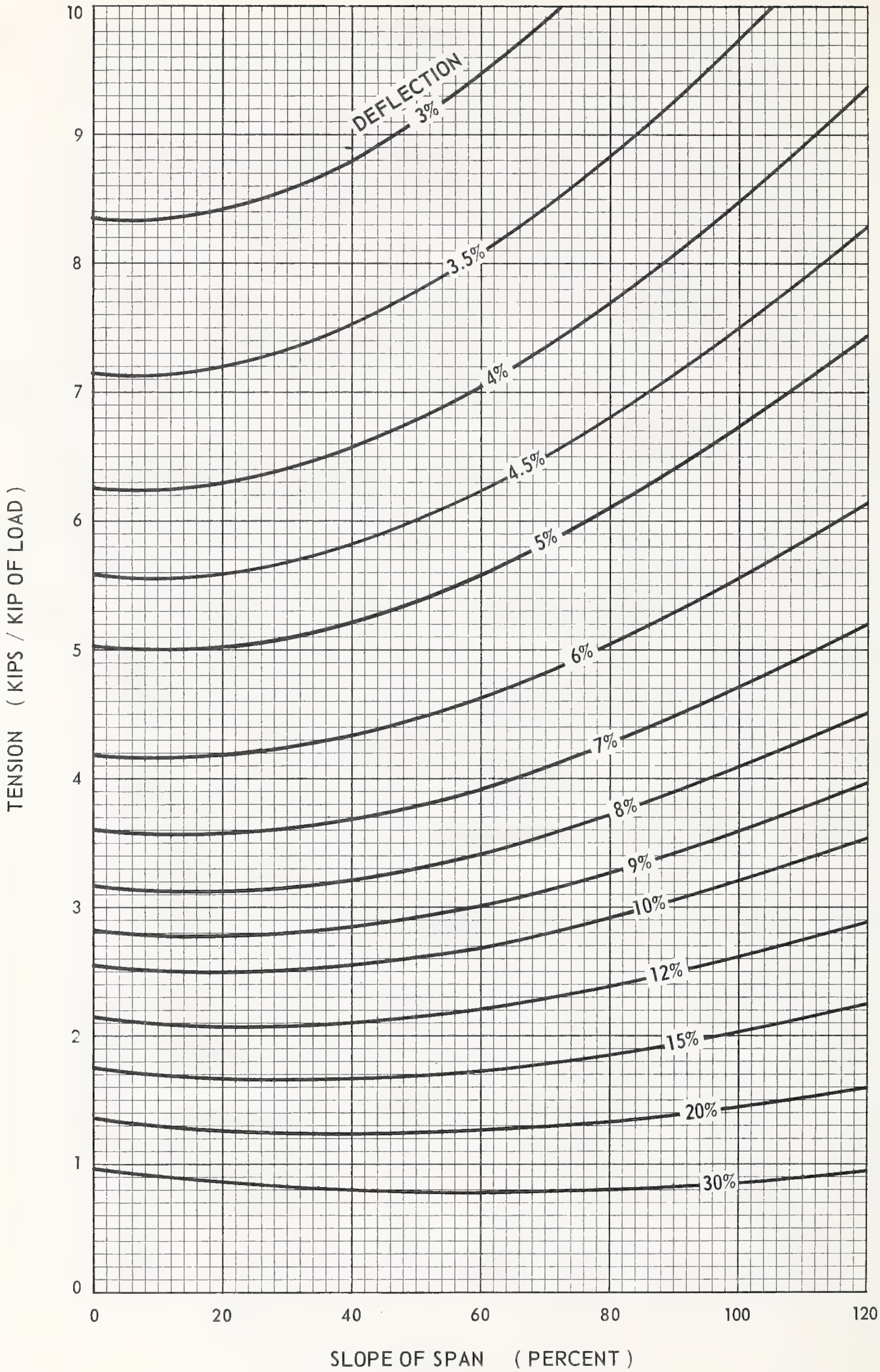

Figure 12.--Tension due to midspan load vs. slope of span for various deflections (carriage not clamped to skyline).

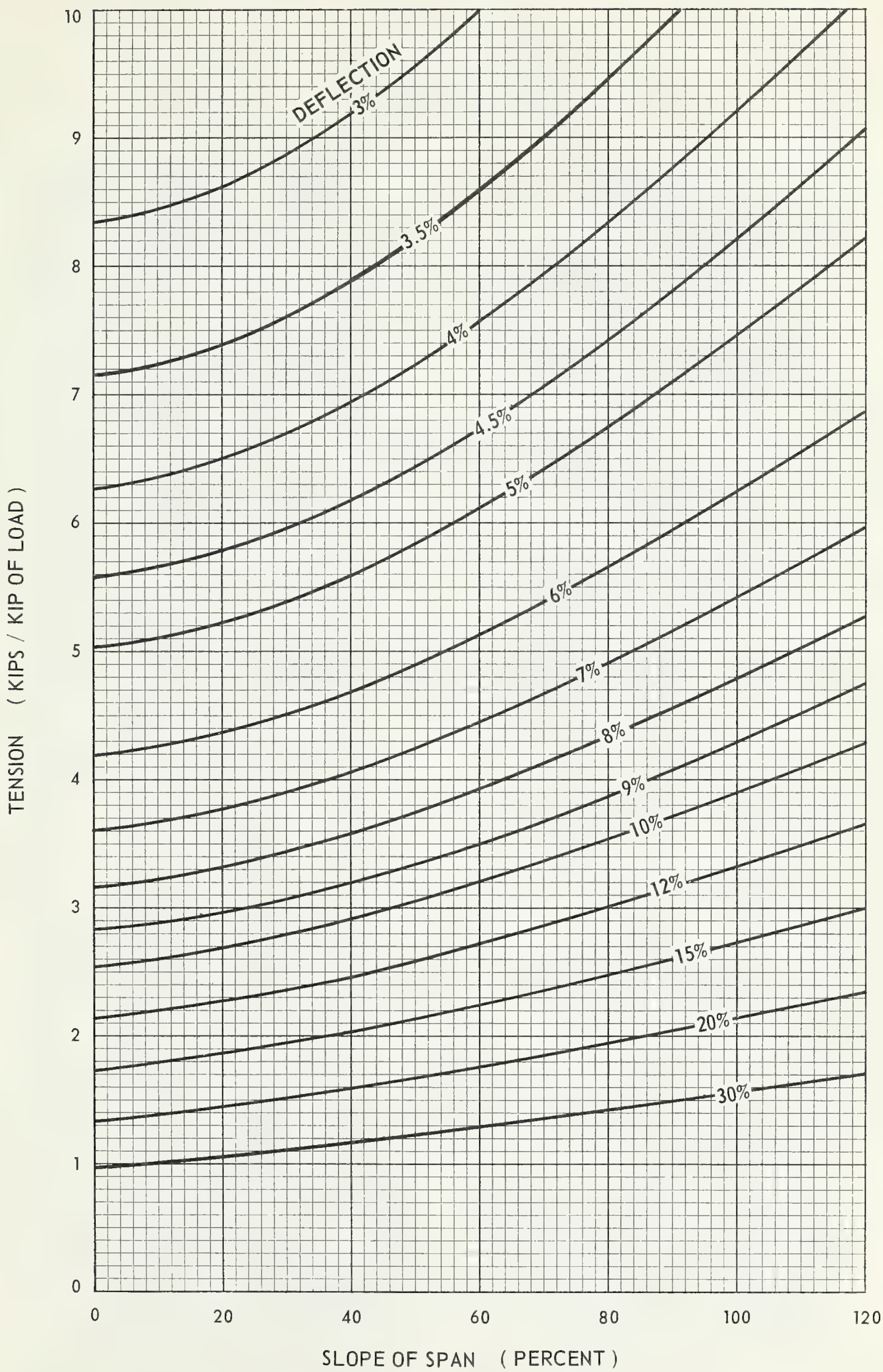

Figure 13.--Upper-end tension due to midspan load vs. slope of span for various deflections (carriage clamped to skyline).

Change in deflection due to load removal vs. load factor for various slopes.

Based on a modulus of elasticity of 14,000,000 p.s.i.

$$\text{Load factor} = \frac{\text{Tension due to load (kips)}}{\text{Tension due to cable weight (kips/station)}}$$

CHANGE IN DEFLECTION DUE TO LOAD REMOVAL (PERCENT)

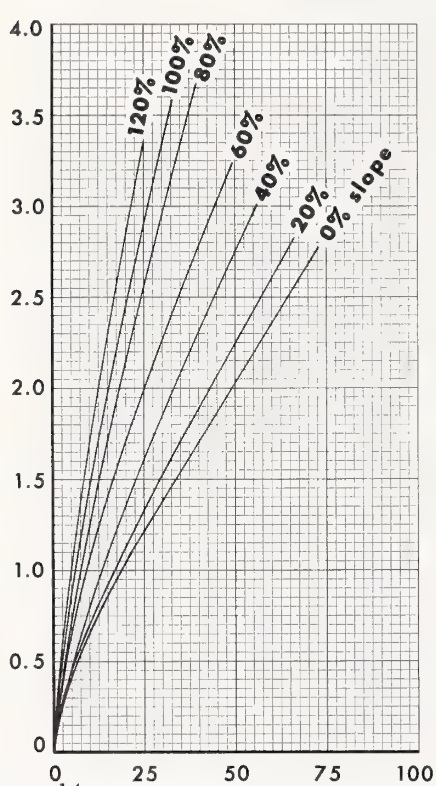

Figure 14
--with a loaded deflection of 5 percent.

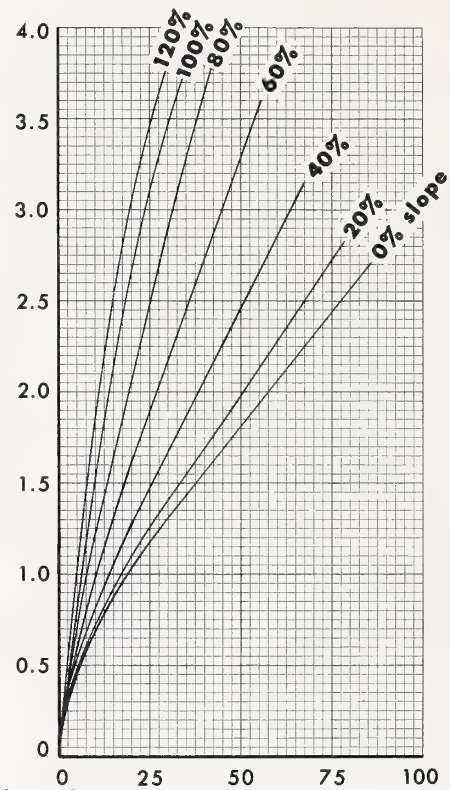

Figure 15
--with a loaded deflection of 6 percent.

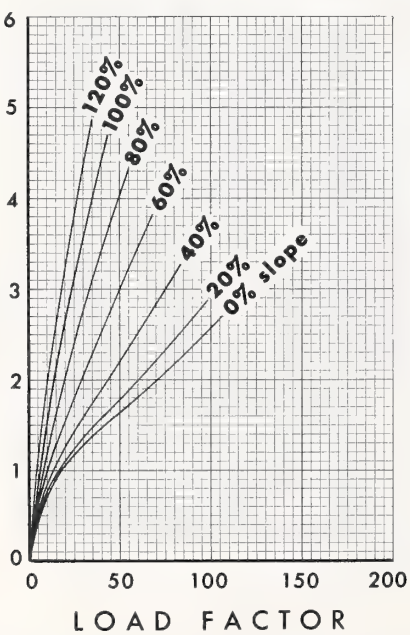

Figure 16
--with a loaded deflection of 7 percent.

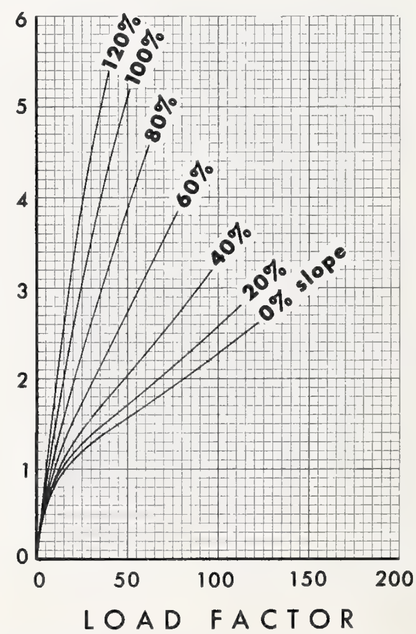

Figure 17
--with a loaded deflection of 8 percent.

Change in deflection due to load removal vs. load factor for various slopes

Based on a modulus of elasticity of 14,000,000 p.s.i.

$$\text{Load factor} = \frac{\text{Tension due to load (kips)}}{\text{Tension due to cable weight (kips/station)}}$$

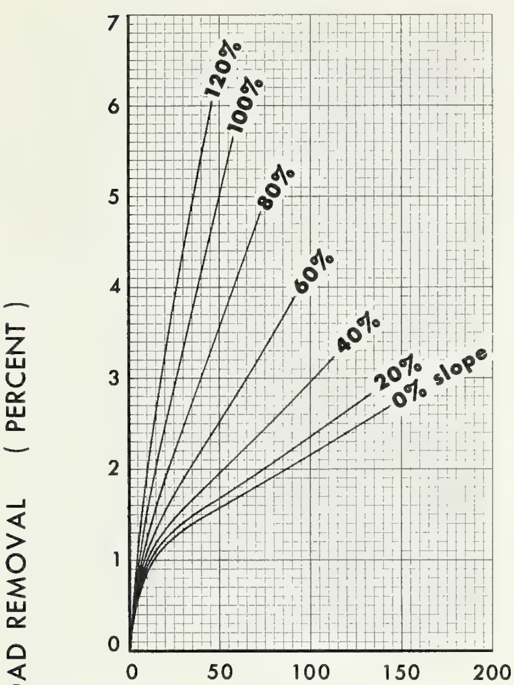

Figure 18
--with a loaded deflection of 9 percent.

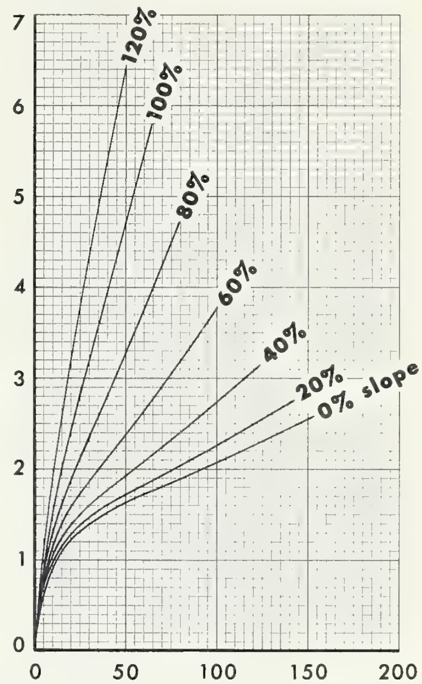

Figure 19
--with a loaded deflection of 10 percent.

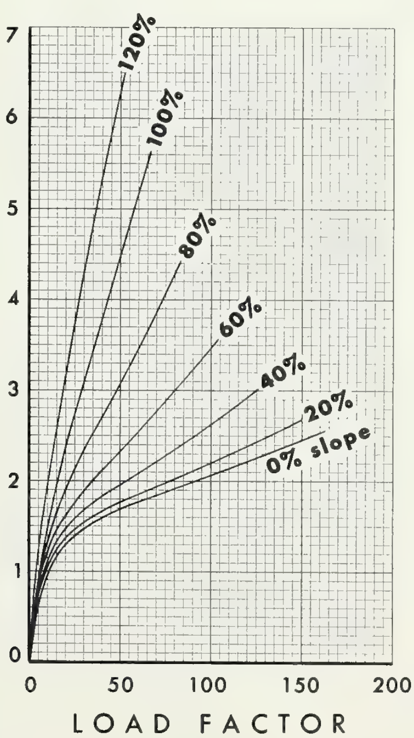

Figure 20
--with a loaded deflection of 11 percent.

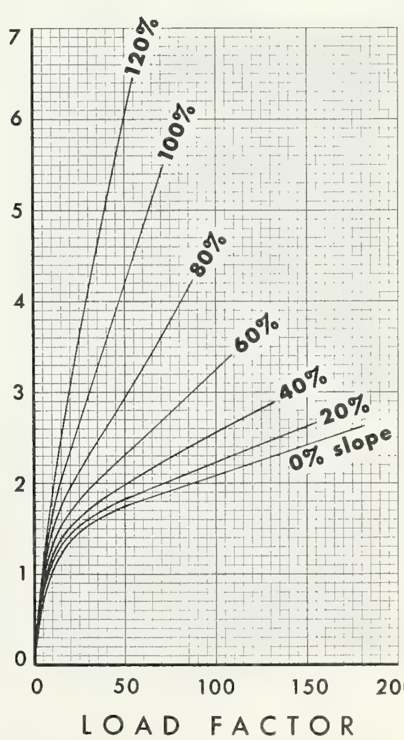

Figure 21
--with a loaded deflection of 12 percent

Change in deflection due to load removal vs. load factor for various slopes

Based on a modulus of elasticity of 14,000,000 p.s.i.

$$\text{Load factor} = \frac{\text{Tension due to load (kips)}}{\text{Tension due to cable weight (kips/station)}}$$

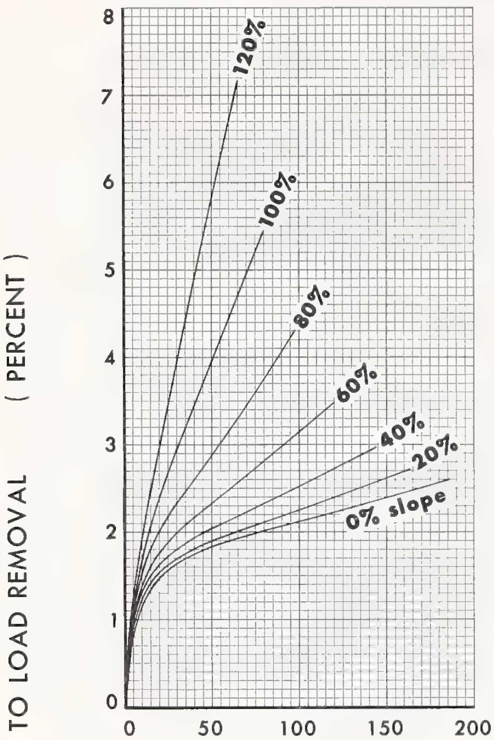

Figure 22
--with a loaded deflection of 13 percent.

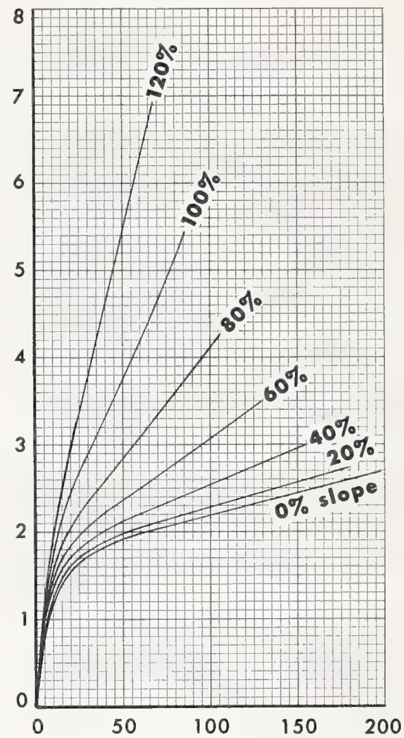

Figure 23
--with a loaded deflection of 14 percent.

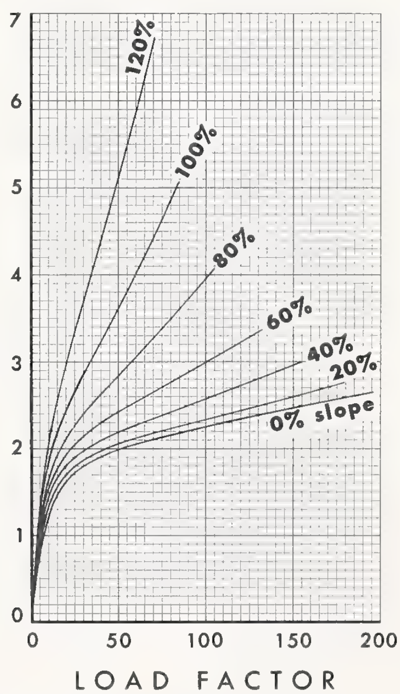

Figure 24
--with a loaded deflection of 15 percent.

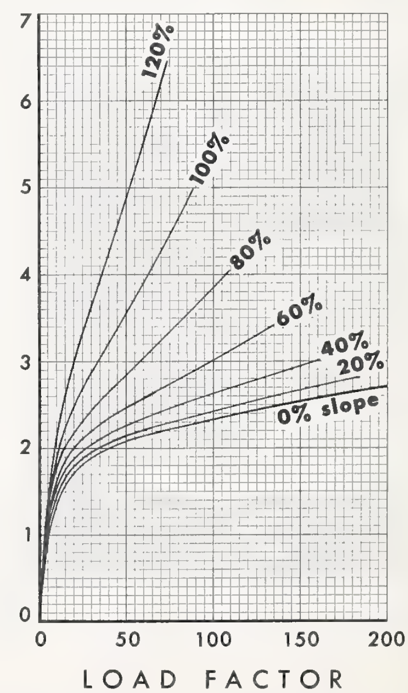

Figure 25
--with a loaded deflection of 16 percent.

Change in deflection due to load removal vs. load factor for various slopes

Based on a modulus of elasticity of 14,000,000 p.s.i.

$$\text{Load factor} = \frac{\text{Tension due to load (kips)}}{\text{Tension due to cable weight (kips/station)}}$$

CHANGE IN DEFLECTION DUE TO LOAD REMOVAL (PERCENT)

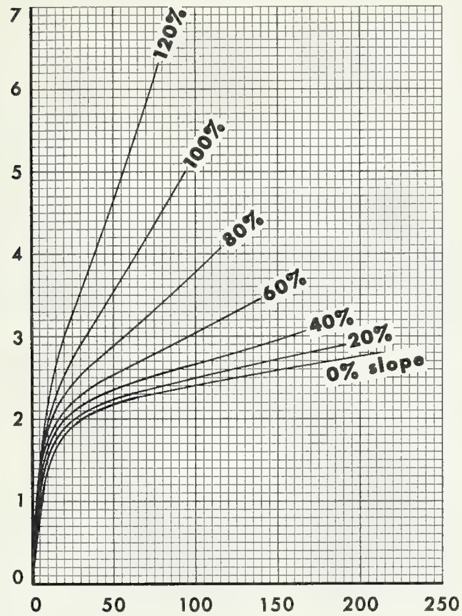

Figure 26
--with a loaded deflection of 17 percent.

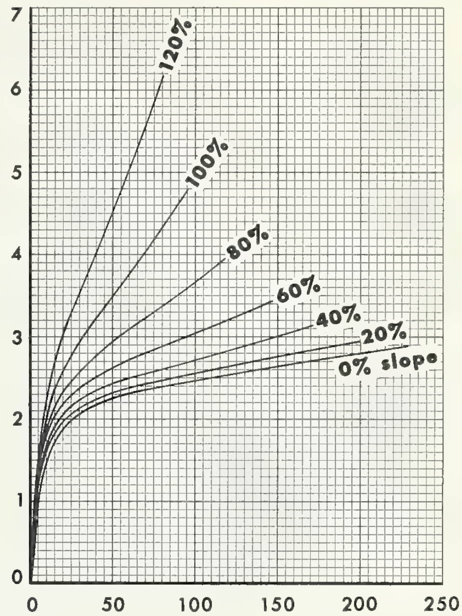

Figure 27
--with a loaded deflection of 18 percent.

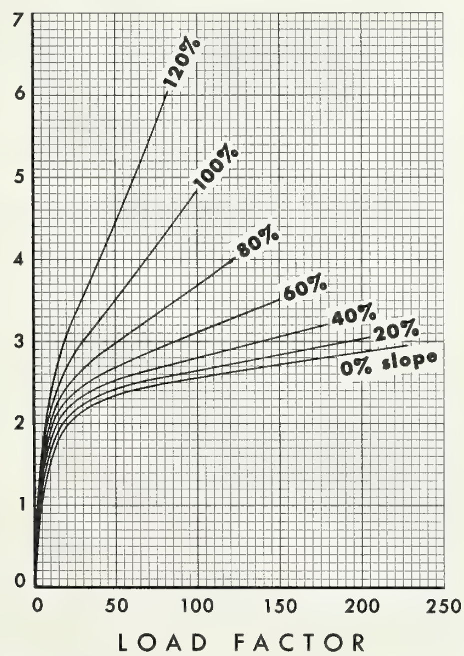

Figure 28
--with a loaded deflection of 19 percent.

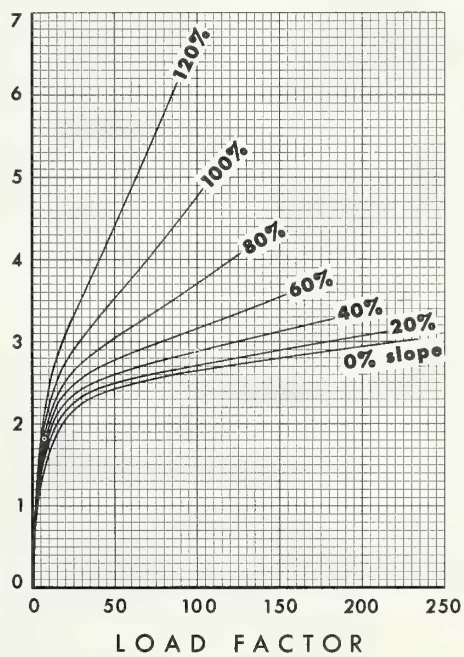

Figure 29
--with a loaded deflection of 20 percent.

Table 2.--Upper-end tension

(In kips per station per

Deflection (percent)	Slope of											
	0	5	10	15	20	25	30	35	40	45	50	55
1.0	1.252	1.257	1.269	1.287	1.312	1.342	1.379	1.422	1.472	1.527	1.589	1.657
1.5	.835	.840	.849	.862	.879	.900	.925	.955	.989	1.027	1.069	1.115
2.0	.628	.632	.639	.649	.663	.679	.699	.722	.747	.776	.809	.844
2.5	.503	.507	.513	.522	.533	.547	.563	.582	.603	.627	.653	.682
3.0	.420	.424	.429	.437	.447	.459	.473	.489	.507	.527	.549	.574
3.5	.361	.365	.370	.377	.386	.396	.408	.422	.438	.456	.475	.497
4.0	.317	.321	.325	.332	.340	.349	.360	.373	.387	.403	.420	.439
4.5	.283	.286	.291	.297	.304	.313	.323	.334	.347	.362	.377	.394
5.0	.256	.259	.263	.269	.276	.284	.293	.304	.316	.329	.343	.359
5.5	.234	.237	.241	.246	.253	.260	.269	.279	.290	.302	.315	.329
6.0	.215	.218	.222	.228	.234	.241	.249	.258	.268	.280	.292	.305
6.5	.200	.203	.207	.212	.218	.224	.232	.241	.250	.261	.272	.285
7.0	.187	.190	.194	.198	.204	.210	.218	.226	.235	.245	.256	.268
7.5	.175	.178	.182	.187	.192	.198	.205	.213	.222	.231	.241	.253
8.0	.166	.169	.172	.177	.182	.188	.194	.202	.210	.219	.229	.240
8.5	.157	.160	.163	.168	.173	.179	.185	.192	.200	.209	.218	.228
9.0	.149	.152	.156	.160	.165	.170	.177	.184	.191	.199	.208	.218
9.5	.143	.146	.149	.153	.158	.163	.169	.176	.183	.191	.200	.209
10.0	.137	.140	.143	.147	.152	.157	.163	.169	.176	.184	.192	.201
10.5	.131	.134	.138	.141	.146	.151	.157	.163	.170	.177	.185	.194
11.0	.127	.129	.133	.137	.141	.146	.151	.157	.164	.171	.179	.187
11.5	.122	.125	.128	.132	.136	.141	.147	.152	.159	.166	.173	.181
12.0	.118	.121	.124	.128	.132	.137	.142	.148	.154	.161	.168	.176
12.5	.115	.117	.121	.124	.128	.133	.138	.144	.150	.157	.164	.171
13.0	.111	.114	.117	.121	.125	.130	.135	.140	.146	.152	.159	.167
13.5	.108	.111	.114	.118	.122	.126	.131	.137	.142	.149	.155	.163
14.0	.106	.108	.112	.115	.119	.123	.128	.134	.139	.145	.152	.159
14.5	.103	.106	.109	.113	.116	.121	.126	.131	.136	.142	.149	.155
15.0	.101	.104	.107	.110	.114	.118	.123	.128	.133	.139	.146	.152
15.5	.099	.101	.105	.108	.112	.116	.121	.126	.131	.137	.143	.149
16.0	.097	.100	.103	.106	.110	.114	.118	.123	.129	.134	.140	.147
16.5	.095	.098	.101	.104	.108	.112	.116	.121	.126	.132	.138	.144
17.0	.093	.096	.099	.102	.106	.110	.115	.119	.124	.130	.136	.142
17.5	.092	.095	.098	.101	.105	.109	.113	.118	.122	.128	.133	.139
18.0	.090	.093	.096	.099	.103	.107	.111	.116	.121	.126	.132	.137
18.5	.089	.092	.095	.098	.102	.106	.110	.114	.119	.124	.130	.136
19.0	.088	.091	.094	.097	.100	.104	.108	.113	.118	.123	.128	.134
19.5	.087	.090	.093	.096	.099	.103	.107	.112	.116	.121	.127	.132
20.0	.086	.089	.091	.095	.098	.102	.106	.110	.115	.120	.125	.131
21.0	.084	.087	.090	.093	.096	.100	.104	.108	.113	.117	.123	.128
22.0	.082	.085	.088	.091	.095	.098	.102	.106	.111	.115	.120	.125
23.0	.081	.084	.087	.090	.093	.097	.101	.105	.109	.114	.118	.123
24.0	.080	.083	.086	.089	.092	.096	.099	.103	.108	.112	.117	.122
25.0	.079	.082	.085	.088	.091	.095	.098	.102	.106	.111	.115	.120
26.0	.078	.081	.084	.087	.090	.094	.097	.101	.105	.109	.114	.119
27.0	.078	.080	.083	.086	.090	.093	.097	.100	.104	.108	.113	.117
28.0	.077	.080	.083	.086	.089	.092	.096	.100	.104	.108	.112	.116
29.0	.077	.080	.082	.085	.089	.092	.095	.099	.103	.107	.111	.116
30.0	.077	.079	.082	.085	.088	.092	.095	.099	.102	.106	.111	.115

due to weight of cable

pound of cable weight per foot)

span (percent)

60	65	70	75	80	85	90	95	100	105	110	115	120
1.731	1.812	1.899	1.992	2.091	2.197	2.309	2.427	2.551	2.682	2.819	2.962	3.111
1.165	1.220	1.278	1.341	1.408	1.480	1.555	1.635	1.718	1.806	1.898	1.995	2.095
.882	.924	.968	1.016	1.067	1.121	1.178	1.239	1.302	1.369	1.438	1.511	1.587
.713	.746	.783	.821	.863	.906	.953	1.001	1.052	1.106	1.162	1.221	1.282
.600	.628	.659	.692	.726	.763	.802	.843	.886	.931	.979	1.028	1.079
.519	.544	.571	.599	.629	.661	.695	.730	.768	.807	.848	.890	.935
.459	.481	.505	.530	.557	.585	.615	.646	.679	.713	.749	.787	.826
.413	.432	.454	.476	.500	.525	.552	.580	.610	.641	.673	.707	.742
.375	.393	.413	.433	.455	.478	.502	.528	.555	.583	.612	.643	.674
.345	.362	.379	.398	.418	.439	.462	.485	.510	.535	.562	.590	.619
.320	.335	.352	.369	.388	.407	.428	.450	.472	.496	.521	.547	.574
.298	.313	.328	.345	.362	.380	.399	.420	.441	.463	.486	.510	.535
.280	.294	.308	.324	.340	.357	.375	.394	.414	.434	.456	.479	.502
.265	.277	.291	.305	.321	.337	.354	.372	.390	.410	.430	.451	.473
.251	.263	.276	.290	.304	.319	.336	.352	.370	.388	.408	.428	.448
.239	.251	.263	.276	.290	.304	.319	.335	.352	.370	.388	.407	.426
.228	.239	.251	.264	.277	.291	.305	.320	.336	.353	.370	.388	.407
.219	.230	.241	.253	.265	.278	.292	.307	.322	.338	.354	.372	.390
.211	.221	.231	.243	.255	.268	.281	.295	.309	.325	.340	.357	.374
.203	.213	.223	.234	.246	.258	.271	.284	.298	.313	.328	.343	.360
.196	.206	.216	.226	.237	.249	.261	.274	.288	.302	.316	.331	.347
.190	.199	.209	.219	.230	.241	.253	.265	.278	.292	.306	.320	.336
.184	.193	.203	.212	.223	.234	.245	.257	.270	.283	.296	.310	.325
.179	.188	.197	.206	.216	.227	.238	.250	.262	.274	.287	.301	.315
.175	.183	.192	.201	.211	.221	.232	.243	.255	.267	.279	.293	.306
.170	.178	.187	.196	.205	.215	.226	.237	.248	.260	.272	.285	.298
.166	.174	.182	.191	.200	.210	.220	.231	.242	.253	.265	.278	.290
.163	.170	.178	.187	.196	.205	.215	.225	.236	.247	.259	.271	.283
.159	.167	.175	.183	.192	.201	.210	.220	.231	.242	.253	.265	.277
.156	.163	.171	.179	.188	.197	.206	.216	.226	.237	.248	.259	.271
.153	.160	.168	.176	.184	.193	.202	.212	.221	.232	.242	.254	.265
.151	.158	.165	.173	.181	.189	.198	.208	.217	.227	.238	.249	.260
.148	.155	.162	.170	.178	.186	.195	.204	.213	.223	.233	.244	.255
.146	.153	.160	.167	.175	.183	.191	.200	.210	.219	.229	.239	.250
.144	.150	.157	.164	.172	.180	.188	.197	.206	.215	.225	.235	.246
.142	.148	.155	.162	.169	.177	.185	.194	.203	.212	.222	.231	.242
.140	.146	.153	.160	.167	.175	.183	.191	.200	.209	.218	.228	.238
.138	.144	.151	.158	.165	.172	.180	.188	.197	.206	.215	.224	.234
.136	.143	.149	.156	.163	.170	.178	.186	.194	.203	.212	.221	.231
.134	.139	.146	.152	.159	.166	.173	.181	.189	.198	.206	.215	.224
.131	.137	.143	.149	.156	.162	.170	.177	.185	.193	.201	.210	.219
.129	.134	.140	.146	.153	.159	.166	.173	.181	.189	.197	.205	.214
.127	.132	.138	.144	.150	.156	.163	.170	.177	.185	.193	.201	.209
.125	.130	.136	.142	.148	.154	.160	.167	.174	.182	.189	.197	.205
.124	.129	.134	.140	.146	.152	.158	.165	.171	.179	.186	.194	.201
.122	.127	.133	.138	.144	.150	.156	.162	.169	.176	.183	.190	.198
.121	.126	.131	.137	.142	.148	.154	.160	.167	.173	.180	.188	.195
.120	.125	.130	.135	.141	.146	.152	.158	.165	.171	.178	.185	.192
.119	.124	.129	.134	.139	.145	.151	.157	.163	.169	.176	.183	.190

Table 3.--Tension due to load

(In kips per

Loaded deflection (percent)	Slope of											
	0	5	10	15	20	25	30	35	40	45	50	55
1.0	25.00	25.01	25.08	25.21	25.40	25.65	25.96	26.33	26.74	27.21	27.73	28.29
1.5	16.67	16.67	16.71	16.78	16.90	17.06	17.26	17.50	17.77	18.07	18.41	18.78
2.0	12.51	12.50	12.52	12.57	12.66	12.77	12.91	13.08	13.28	13.51	13.76	14.03
2.5	10.01	10.00	10.01	10.05	10.11	10.19	10.30	10.44	10.59	10.77	10.96	11.18
3.0	8.34	8.33	8.34	8.36	8.41	8.48	8.57	8.67	8.80	8.94	9.10	9.28
3.5	7.16	7.14	7.14	7.16	7.20	7.25	7.33	7.41	7.52	7.64	7.77	7.92
4.0	6.27	6.25	6.25	6.26	6.29	6.34	6.40	6.47	6.56	6.66	6.77	6.90
4.5	5.57	5.56	5.55	5.56	5.58	5.62	5.67	5.74	5.81	5.90	6.00	6.11
5.0	5.02	5.00	5.00	5.00	5.02	5.05	5.09	5.15	5.22	5.29	5.38	5.48
5.5	4.57	4.55	4.54	4.54	4.56	4.58	4.62	4.67	4.73	4.80	4.87	4.96
6.0	4.19	4.17	4.16	4.16	4.17	4.20	4.23	4.27	4.32	4.38	4.45	4.53
6.5	3.87	3.85	3.84	3.84	3.85	3.87	3.90	3.93	3.98	4.03	4.10	4.17
7.0	3.60	3.58	3.57	3.57	3.57	3.59	3.61	3.64	3.68	3.73	3.79	3.85
7.5	3.37	3.35	3.33	3.33	3.33	3.34	3.36	3.39	3.43	3.47	3.53	3.58
8.0	3.16	3.14	3.13	3.12	3.12	3.13	3.15	3.17	3.21	3.25	3.29	3.35
8.5	2.98	2.96	2.94	2.94	2.94	2.94	2.96	2.98	3.01	3.05	3.09	3.14
9.0	2.82	2.80	2.78	2.77	2.77	2.78	2.79	2.81	2.84	2.87	2.91	2.95
9.5	2.67	2.65	2.64	2.63	2.62	2.63	2.64	2.66	2.68	2.71	2.75	2.79
10.0	2.54	2.52	2.51	2.50	2.49	2.50	2.50	2.52	2.54	2.57	2.60	2.64
10.5	2.43	2.41	2.39	2.38	2.37	2.37	2.38	2.40	2.41	2.44	2.47	2.51
11.0	2.32	2.30	2.28	2.27	2.27	2.27	2.27	2.28	2.30	2.32	2.35	2.38
11.5	2.23	2.20	2.19	2.17	2.17	2.17	2.17	2.18	2.19	2.22	2.24	2.27
12.0	2.14	2.11	2.10	2.08	2.08	2.07	2.08	2.09	2.10	2.12	2.14	2.17
12.5	2.06	2.03	2.02	2.00	1.99	1.99	1.99	2.00	2.01	2.03	2.05	2.08
13.0	1.98	1.96	1.94	1.93	1.92	1.91	1.91	1.92	1.93	1.95	1.97	1.99
13.5	1.91	1.89	1.87	1.86	1.85	1.84	1.84	1.85	1.85	1.87	1.89	1.91
14.0	1.85	1.83	1.81	1.79	1.78	1.78	1.77	1.78	1.79	1.80	1.81	1.84
14.5	1.79	1.77	1.75	1.73	1.72	1.71	1.71	1.71	1.72	1.73	1.75	1.77
15.0	1.74	1.71	1.69	1.68	1.66	1.66	1.65	1.65	1.66	1.67	1.68	1.70
15.5	1.68	1.66	1.64	1.62	1.61	1.60	1.60	1.60	1.60	1.61	1.63	1.64
16.0	1.64	1.61	1.59	1.57	1.56	1.55	1.55	1.55	1.55	1.56	1.57	1.59
16.5	1.59	1.57	1.55	1.53	1.52	1.51	1.50	1.50	1.50	1.51	1.52	1.53
17.0	1.55	1.52	1.50	1.49	1.47	1.46	1.46	1.45	1.46	1.46	1.47	1.48
17.5	1.51	1.48	1.46	1.45	1.43	1.42	1.41	1.41	1.41	1.42	1.43	1.44
18.0	1.47	1.45	1.43	1.41	1.39	1.38	1.37	1.37	1.37	1.37	1.38	1.39
18.5	1.44	1.41	1.39	1.37	1.36	1.34	1.34	1.33	1.33	1.34	1.34	1.35
19.0	1.40	1.38	1.36	1.34	1.32	1.31	1.30	1.30	1.30	1.30	1.30	1.31
19.5	1.37	1.35	1.32	1.31	1.29	1.28	1.27	1.26	1.26	1.26	1.27	1.28
20.0	1.34	1.32	1.29	1.27	1.26	1.25	1.24	1.23	1.23	1.23	1.23	1.24
21.0	1.29	1.26	1.24	1.22	1.20	1.19	1.18	1.17	1.17	1.17	1.17	1.18
22.0	1.24	1.21	1.19	1.17	1.15	1.14	1.12	1.12	1.11	1.11	1.11	1.12
23.0	1.19	1.17	1.14	1.12	1.10	1.09	1.08	1.07	1.06	1.06	1.06	1.06
24.0	1.15	1.12	1.10	1.08	1.06	1.04	1.03	1.02	1.01	1.01	1.01	1.01
25.0	1.11	1.09	1.06	1.04	1.02	1.01	.99	.98	.97	.97	.97	.97
26.0	1.08	1.05	1.03	1.01	.99	.97	.95	.94	.93	.93	.93	.93
27.0	1.05	1.02	1.00	.97	.95	.94	.92	.91	.90	.89	.89	.89
28.0	1.02	.99	.97	.94	.92	.90	.89	.88	.87	.86	.85	.85
29.0	.99	.96	.94	.92	.89	.88	.86	.85	.83	.83	.82	.82
30.0	.97	.94	.91	.89	.87	.85	.83	.82	.81	.80	.79	.79

(carriage not clamped to skyline)

kip of load)

span (percent)

60	65	70	75	80	85	90	95	100	105	110	115	120
28.90	29.55	30.23	30.95	31.70	32.49	33.30	34.14	35.00	35.89	36.79	37.72	38.67
19.18	19.61	20.06	20.53	21.03	21.55	22.09	22.64	23.22	23.80	24.41	25.02	25.65
14.32	14.64	14.97	15.33	15.70	16.08	16.48	16.90	17.32	17.76	18.21	18.67	19.14
11.41	11.66	11.92	12.20	12.50	12.80	13.12	13.45	13.79	14.14	14.50	14.86	15.24
9.47	9.67	9.89	10.12	10.36	10.62	10.88	11.15	11.43	11.72	12.02	12.32	12.63
8.08	8.25	8.44	8.63	8.84	9.05	9.28	9.51	9.75	10.00	10.25	10.51	10.77
7.04	7.19	7.35	7.52	7.70	7.88	8.08	8.28	8.49	8.70	8.92	9.15	9.38
6.23	6.36	6.50	6.65	6.81	6.97	7.14	7.32	7.51	7.70	7.89	8.09	8.30
5.59	5.70	5.83	5.96	6.10	6.25	6.40	6.56	6.72	6.89	7.07	7.25	7.43
5.06	5.16	5.27	5.39	5.52	5.65	5.79	5.93	6.08	6.23	6.39	6.55	6.72
4.62	4.71	4.81	4.92	5.03	5.15	5.28	5.41	5.55	5.68	5.83	5.98	6.13
4.24	4.33	4.42	4.52	4.62	4.73	4.85	4.97	5.09	5.22	5.35	5.49	5.63
3.92	4.00	4.09	4.18	4.27	4.37	4.48	4.59	4.70	4.82	4.95	5.07	5.20
3.65	3.72	3.80	3.88	3.97	4.06	4.16	4.26	4.37	4.48	4.59	4.71	4.83
3.41	3.47	3.54	3.62	3.70	3.79	3.88	3.98	4.08	4.18	4.28	4.39	4.50
3.19	3.26	3.32	3.39	3.47	3.55	3.63	3.72	3.82	3.91	4.01	4.11	4.22
3.01	3.06	3.12	3.19	3.26	3.34	3.42	3.50	3.59	3.68	3.77	3.86	3.96
2.84	2.89	2.95	3.01	3.07	3.15	3.22	3.30	3.38	3.46	3.55	3.64	3.73
2.68	2.73	2.79	2.84	2.91	2.97	3.04	3.12	3.19	3.27	3.36	3.44	3.53
2.55	2.59	2.64	2.70	2.76	2.82	2.88	2.95	3.03	3.10	3.18	3.26	3.34
2.42	2.46	2.51	2.56	2.62	2.68	2.74	2.81	2.87	2.95	3.02	3.10	3.17
2.31	2.35	2.39	2.44	2.49	2.55	2.61	2.67	2.74	2.80	2.87	2.95	3.02
2.20	2.24	2.28	2.33	2.38	2.43	2.49	2.55	2.61	2.67	2.74	2.81	2.88
2.11	2.14	2.18	2.23	2.27	2.32	2.38	2.43	2.49	2.55	2.62	2.68	2.75
2.02	2.05	2.09	2.13	2.17	2.22	2.27	2.33	2.38	2.44	2.50	2.57	2.63
1.94	1.97	2.00	2.04	2.08	2.13	2.18	2.23	2.28	2.34	2.40	2.46	2.52
1.86	1.89	1.92	1.96	2.00	2.04	2.09	2.14	2.19	2.24	2.30	2.36	2.42
1.79	1.82	1.85	1.88	1.92	1.96	2.01	2.05	2.10	2.16	2.21	2.26	2.32
1.73	1.75	1.78	1.81	1.85	1.89	1.93	1.98	2.02	2.07	2.12	2.18	2.23
1.66	1.69	1.72	1.75	1.78	1.82	1.86	1.90	1.95	2.00	2.04	2.10	2.15
1.61	1.63	1.66	1.69	1.72	1.75	1.79	1.83	1.88	1.92	1.97	2.02	2.07
1.55	1.57	1.60	1.63	1.66	1.69	1.73	1.77	1.81	1.85	1.90	1.95	2.00
1.50	1.52	1.55	1.57	1.60	1.64	1.67	1.71	1.75	1.79	1.83	1.88	1.93
1.45	1.47	1.50	1.52	1.55	1.58	1.62	1.65	1.69	1.73	1.77	1.82	1.86
1.41	1.43	1.45	1.47	1.50	1.53	1.56	1.60	1.63	1.67	1.71	1.76	1.80
1.37	1.38	1.40	1.43	1.45	1.48	1.51	1.55	1.58	1.62	1.66	1.70	1.74
1.33	1.34	1.36	1.38	1.41	1.44	1.47	1.50	1.53	1.57	1.61	1.65	1.69
1.29	1.30	1.32	1.34	1.37	1.39	1.42	1.45	1.49	1.52	1.56	1.60	1.64
1.25	1.27	1.28	1.30	1.33	1.35	1.38	1.41	1.44	1.47	1.51	1.55	1.59
1.18	1.20	1.21	1.23	1.25	1.27	1.30	1.33	1.36	1.39	1.42	1.46	1.49
1.12	1.13	1.15	1.16	1.18	1.21	1.23	1.25	1.28	1.31	1.34	1.38	1.41
1.07	1.08	1.09	1.10	1.12	1.14	1.16	1.19	1.21	1.24	1.27	1.30	1.34
1.02	1.03	1.04	1.05	1.07	1.08	1.10	1.13	1.15	1.18	1.21	1.23	1.27
.97	.98	.99	1.00	1.01	1.03	1.05	1.07	1.09	1.12	1.14	1.17	1.20
.93	.93	.94	.95	.97	.98	1.00	1.02	1.04	1.06	1.09	1.11	1.14
.89	.89	.90	.91	.92	.94	.95	.97	.99	1.01	1.04	1.06	1.09
.85	.86	.86	.87	.88	.89	.91	.93	.95	.97	.99	1.01	1.04
.82	.82	.83	.83	.84	.86	.87	.89	.90	.92	.94	.97	.99
.79	.79	.79	.80	.81	.82	.83	.85	.86	.88	.90	.92	.95

Table 4.--Upper-end tension due to

(In kips per

Loaded deflection (percent)	Slope of											
	0	5	10	15	20	25	30	35	40	45	50	55
1.0	25.00	25.06	25.18	25.36	25.60	25.89	26.25	26.66	27.11	27.62	28.18	28.78
1.5	16.67	16.72	16.80	16.93	17.10	17.31	17.55	17.83	18.14	18.48	18.86	19.26
2.0	12.51	12.55	12.62	12.72	12.85	13.01	13.20	13.41	13.65	13.92	14.20	14.51
2.5	10.01	10.05	10.11	10.19	10.30	10.44	10.59	10.77	10.96	11.18	11.41	11.66
3.0	8.34	8.38	8.44	8.51	8.61	8.72	8.85	9.00	9.17	9.35	9.55	9.76
3.5	7.16	7.19	7.24	7.31	7.39	7.50	7.61	7.74	7.89	8.05	8.22	8.40
4.0	6.27	6.30	6.35	6.41	6.49	6.58	6.68	6.80	6.93	7.07	7.22	7.38
4.5	5.57	5.61	5.65	5.71	5.78	5.86	5.96	6.07	6.18	6.31	6.45	6.59
5.0	5.02	5.05	5.09	5.15	5.22	5.29	5.38	5.48	5.59	5.70	5.83	5.96
5.5	4.57	4.60	4.64	4.69	4.75	4.83	4.91	5.00	5.10	5.21	5.32	5.44
6.0	4.19	4.22	4.26	4.31	4.37	4.44	4.51	4.60	4.69	4.79	4.90	5.01
6.5	3.87	3.90	3.94	3.99	4.05	4.11	4.18	4.26	4.35	4.44	4.54	4.65
7.0	3.60	3.63	3.67	3.71	3.77	3.83	3.90	3.97	4.05	4.14	4.24	4.33
7.5	3.37	3.39	3.43	3.48	3.53	3.59	3.65	3.72	3.80	3.88	3.97	4.06
8.0	3.16	3.18	3.22	3.27	3.32	3.37	3.44	3.50	3.58	3.66	3.74	3.83
8.5	2.98	3.01	3.04	3.08	3.13	3.19	3.25	3.31	3.38	3.46	3.54	3.62
9.0	2.82	2.85	2.88	2.92	2.97	3.02	3.08	3.14	3.21	3.28	3.35	3.43
9.5	2.67	2.70	2.74	2.77	2.82	2.87	2.93	2.99	3.05	3.12	3.19	3.27
10.0	2.54	2.57	2.61	2.64	2.69	2.74	2.79	2.85	2.91	2.98	3.05	3.12
10.5	2.43	2.46	2.49	2.53	2.57	2.62	2.67	2.72	2.78	2.85	2.91	2.99
11.0	2.32	2.35	2.38	2.42	2.46	2.51	2.56	2.61	2.67	2.73	2.80	2.86
11.5	2.23	2.25	2.28	2.32	2.36	2.41	2.46	2.51	2.56	2.62	2.69	2.75
12.0	2.14	2.16	2.20	2.23	2.27	2.32	2.36	2.41	2.47	2.53	2.59	2.65
12.5	2.06	2.08	2.11	2.15	2.19	2.23	2.28	2.33	2.38	2.44	2.49	2.56
13.0	1.98	2.01	2.04	2.07	2.11	2.15	2.20	2.25	2.30	2.35	2.41	2.47
13.5	1.91	1.94	1.97	2.00	2.04	2.08	2.13	2.17	2.22	2.28	2.33	2.39
14.0	1.85	1.88	1.91	1.94	1.98	2.02	2.06	2.11	2.15	2.21	2.26	2.32
14.5	1.79	1.82	1.85	1.88	1.91	1.95	2.00	2.04	2.09	2.14	2.19	2.25
15.0	1.74	1.76	1.79	1.82	1.86	1.90	1.94	1.98	2.03	2.08	2.13	2.18
15.5	1.68	1.71	1.74	1.77	1.81	1.84	1.88	1.93	1.97	2.02	2.07	2.12
16.0	1.64	1.66	1.69	1.72	1.76	1.79	1.83	1.88	1.92	1.97	2.02	2.07
16.5	1.59	1.62	1.64	1.68	1.71	1.75	1.79	1.83	1.87	1.92	1.96	2.01
17.0	1.55	1.57	1.60	1.63	1.67	1.70	1.74	1.78	1.82	1.87	1.92	1.96
17.5	1.51	1.53	1.56	1.59	1.63	1.66	1.70	1.74	1.78	1.82	1.87	1.92
18.0	1.47	1.50	1.52	1.55	1.59	1.62	1.66	1.70	1.74	1.78	1.83	1.87
18.5	1.44	1.46	1.49	1.52	1.55	1.58	1.62	1.66	1.70	1.74	1.79	1.83
19.0	1.40	1.43	1.45	1.48	1.52	1.55	1.59	1.62	1.66	1.70	1.75	1.79
19.5	1.37	1.40	1.42	1.45	1.48	1.52	1.55	1.59	1.63	1.67	1.71	1.75
20.0	1.34	1.37	1.39	1.42	1.45	1.49	1.52	1.56	1.60	1.63	1.68	1.72
21.0	1.29	1.31	1.34	1.37	1.40	1.43	1.46	1.50	1.53	1.57	1.61	1.65
22.0	1.24	1.26	1.29	1.31	1.34	1.38	1.41	1.44	1.48	1.52	1.55	1.59
23.0	1.19	1.22	1.24	1.27	1.30	1.33	1.36	1.39	1.43	1.46	1.50	1.54
24.0	1.15	1.17	1.20	1.23	1.25	1.28	1.32	1.35	1.38	1.42	1.45	1.49
25.0	1.11	1.14	1.16	1.19	1.22	1.24	1.28	1.31	1.34	1.37	1.41	1.44
26.0	1.08	1.10	1.13	1.15	1.18	1.21	1.24	1.27	1.30	1.33	1.37	1.40
27.0	1.05	1.07	1.09	1.12	1.15	1.17	1.20	1.23	1.27	1.30	1.33	1.36
28.0	1.02	1.04	1.06	1.09	1.12	1.14	1.17	1.20	1.23	1.26	1.30	1.33
29.0	.99	1.01	1.04	1.06	1.09	1.11	1.14	1.17	1.20	1.23	1.26	1.29
30.0	.97	.99	1.01	1.04	1.06	1.09	1.12	1.14	1.17	1.20	1.23	1.26

load (carriage clamped to skyline)

kip of load)

span (percent)

60	65	70	75	80	85	90	95	100	105	110	115	120
29.41	30.09	30.80	31.55	32.33	33.14	33.97	34.83	35.71	36.61	37.53	38.48	39.43
19.70	20.15	20.63	21.13	21.66	22.20	22.76	23.33	23.92	24.53	25.15	25.78	26.42
14.84	15.18	15.55	15.93	16.32	16.73	17.15	17.59	18.03	18.49	18.95	19.43	19.91
11.92	12.20	12.50	12.80	13.12	13.45	13.79	14.14	14.50	14.86	15.24	15.62	16.00
9.98	10.22	10.46	10.72	10.99	11.26	11.55	11.84	12.14	12.45	12.76	13.08	13.40
8.59	8.80	9.01	9.23	9.46	9.70	9.95	10.20	10.46	10.72	10.99	11.26	11.54
7.55	7.73	7.92	8.12	8.32	8.53	8.75	8.97	9.19	9.43	9.66	9.90	10.15
6.75	6.91	7.08	7.25	7.43	7.62	7.81	8.01	8.21	8.42	8.63	8.85	9.06
6.10	6.25	6.40	6.56	6.72	6.89	7.07	7.25	7.43	7.62	7.81	8.00	8.20
5.57	5.70	5.84	5.99	6.14	6.30	6.46	6.62	6.79	6.96	7.13	7.31	7.49
5.13	5.25	5.38	5.52	5.66	5.80	5.95	6.10	6.25	6.41	6.57	6.73	6.90
4.76	4.87	4.99	5.12	5.25	5.38	5.52	5.66	5.80	5.94	6.09	6.24	6.40
4.44	4.55	4.66	4.78	4.90	5.02	5.15	5.28	5.41	5.55	5.68	5.82	5.97
4.16	4.26	4.37	4.48	4.59	4.71	4.83	4.95	5.07	5.20	5.33	5.46	5.60
3.92	4.02	4.12	4.22	4.33	4.44	4.55	4.66	4.78	4.90	5.02	5.15	5.27
3.71	3.80	3.89	3.99	4.09	4.20	4.30	4.41	4.52	4.63	4.75	4.87	4.98
3.52	3.60	3.70	3.79	3.88	3.98	4.08	4.19	4.29	4.40	4.51	4.62	4.73
3.35	3.43	3.52	3.61	3.70	3.79	3.89	3.99	4.09	4.19	4.29	4.39	4.50
3.20	3.28	3.36	3.44	3.53	3.62	3.71	3.80	3.90	4.00	4.09	4.19	4.30
3.06	3.14	3.21	3.30	3.38	3.46	3.55	3.64	3.73	3.82	3.92	4.01	4.11
2.93	3.01	3.08	3.16	3.24	3.32	3.41	3.49	3.58	3.67	3.76	3.85	3.94
2.82	2.89	2.96	3.04	3.12	3.19	3.27	3.36	3.44	3.53	3.61	3.70	3.79
2.72	2.78	2.85	2.93	3.00	3.08	3.15	3.23	3.31	3.39	3.48	3.56	3.65
2.62	2.69	2.75	2.82	2.89	2.97	3.04	3.12	3.20	3.27	3.35	3.44	3.52
2.53	2.59	2.66	2.73	2.80	2.87	2.94	3.01	3.09	3.16	3.24	3.32	3.40
2.45	2.51	2.57	2.64	2.71	2.77	2.84	2.92	2.99	3.06	3.14	3.21	3.29
2.37	2.43	2.49	2.56	2.62	2.69	2.76	2.83	2.89	2.97	3.04	3.11	3.18
2.30	2.36	2.42	2.48	2.54	2.61	2.67	2.74	2.81	2.88	2.95	3.02	3.09
2.24	2.29	2.35	2.41	2.47	2.53	2.60	2.66	2.73	2.79	2.86	2.93	3.00
2.18	2.23	2.29	2.34	2.40	2.46	2.53	2.59	2.65	2.72	2.78	2.85	2.92
2.12	2.17	2.23	2.28	2.34	2.40	2.46	2.52	2.58	2.64	2.71	2.77	2.84
2.06	2.12	2.17	2.22	2.28	2.34	2.40	2.46	2.52	2.58	2.64	2.70	2.76
2.01	2.06	2.12	2.17	2.22	2.28	2.34	2.39	2.45	2.51	2.57	2.63	2.69
1.96	2.01	2.07	2.12	2.17	2.23	2.28	2.34	2.39	2.45	2.51	2.57	2.63
1.92	1.97	2.02	2.07	2.12	2.17	2.23	2.28	2.34	2.40	2.45	2.51	2.57
1.88	1.92	1.97	2.02	2.07	2.13	2.18	2.23	2.29	2.34	2.40	2.45	2.51
1.84	1.88	1.93	1.98	2.03	2.08	2.13	2.18	2.24	2.29	2.34	2.40	2.45
1.80	1.84	1.89	1.94	1.99	2.04	2.09	2.14	2.19	2.24	2.29	2.35	2.40
1.76	1.81	1.85	1.90	1.95	2.00	2.04	2.09	2.14	2.20	2.25	2.30	2.35
1.69	1.74	1.78	1.83	1.87	1.92	1.97	2.01	2.06	2.11	2.16	2.21	2.26
1.63	1.68	1.72	1.76	1.80	1.85	1.89	1.94	1.99	2.03	2.08	2.13	2.18
1.58	1.62	1.66	1.70	1.74	1.79	1.83	1.87	1.92	1.96	2.01	2.05	2.10
1.53	1.57	1.61	1.65	1.69	1.73	1.77	1.81	1.85	1.90	1.94	1.99	2.03
1.48	1.52	1.56	1.59	1.63	1.67	1.71	1.76	1.80	1.84	1.88	1.92	1.97
1.44	1.47	1.51	1.55	1.59	1.62	1.66	1.70	1.74	1.78	1.82	1.87	1.91
1.40	1.43	1.47	1.51	1.54	1.58	1.62	1.66	1.69	1.73	1.77	1.81	1.85
1.36	1.40	1.43	1.47	1.50	1.54	1.57	1.61	1.65	1.69	1.72	1.76	1.80
1.33	1.36	1.39	1.43	1.46	1.50	1.53	1.57	1.61	1.64	1.68	1.72	1.75
1.30	1.33	1.36	1.39	1.43	1.46	1.50	1.53	1.57	1.60	1.64	1.67	1.71

Table 5.--Ratio of catenary curve length

Unloaded deflection (percent)	Slope of											
	0	5	10	15	20	25	30	35	40	45	50	55
1.0	1.00027	1.00151	1.00525	1.01145	1.02006	1.03102	1.04426	1.05971	1.07725	1.09679	1.11822	1.14145
1.5	1.00060	1.00185	1.00558	1.01177	1.02037	1.03132	1.04456	1.05999	1.07751	1.09704	1.11846	1.14167
2.0	1.00107	1.00231	1.00604	1.01222	1.02081	1.03175	1.04497	1.06038	1.07789	1.09739	1.11880	1.14199
2.5	1.00166	1.00291	1.00663	1.01280	1.02137	1.03230	1.04549	1.06088	1.07837	1.09785	1.11923	1.14239
3.0	1.00239	1.00363	1.00735	1.01350	1.02206	1.03296	1.04614	1.06150	1/07895	1.09840	1.11975	1.14288
3.5	1.00326	1.00449	1.00820	1.01434	1.02288	1.03375	1.04689	1.06222	1.07964	1.09906	1.12037	1.14347
4.0	1.00425	1.00548	1.00917	1.01530	1.02381	1.03466	1.04777	1.06306	1.08044	1.09982	1.12108	1.14414
4.5	1.00537	1.00660	1.01028	1.01639	1.02487	1.03569	1.04876	1.06401	1.08134	1.10067	1.12189	1.14490
5.0	1.00663	1.00785	1.01152	1.01760	1.02606	1.03683	1.04986	1.06506	1.08235	1.10163	1.12279	1.14575
5.5	1.00801	1.00923	1.01288	1.01894	1.02736	1.03810	1.05108	1.06623	1.08346	1.10268	1.12379	1.14669
6.0	1.00951	1.01073	1.01436	1.02040	1.02879	1.03948	1.05241	1.06751	1.08468	1.10384	1.12488	1.14771
6.5	1.01115	1.01236	1.01598	1.02198	1.03033	1.04098	1.05386	1.06889	1.08600	1.10509	1.12606	1.14883
7.0	1.01291	1.01411	1.01771	1.02368	1.03199	1.04259	1.05541	1.07038	1.08742	1.10644	1.12734	1.15003
7.5	1.01479	1.01599	1.01957	1.02551	1.03378	1.04432	1.05708	1.07198	1.08895	1.10789	1.12871	1.15132
8.0	1.01680	1.01799	1.02155	1.02746	1.03568	1.04616	1.05886	1.07369	1.09057	1.10943	1.13017	1.15270
8.5	1.01893	1.02011	1.02365	1.02952	1.03769	1.04812	1.06074	1.07550	1.09230	1.11107	1.13173	1.15416
9.0	1.02118	1.02235	1.02586	1.03170	1.03982	1.05019	1.06274	1.07741	1.09413	1.11281	1.13337	1.15571
9.5	1.02354	1.02471	1.02820	1.03400	1.04207	1.05237	1.06484	1.07943	1.09606	1.11465	1.13511	1.15735
10.0	1.02603	1.02718	1.03065	1.03641	1.04442	1.05466	1.06705	1.08156	1.09809	1.11658	1.13694	1.15908
10.5	1.02863	1.02977	1.03321	1.03893	1.04689	1.05705	1.06937	1.08378	1.10022	1.11860	1.13885	1.16089
11.0	1.03134	1.03248	1.03589	1.04156	1.04946	1.05956	1.07179	1.08611	1.10244	1.12072	1.14086	1.16278
11.5	1.03416	1.03530	1.03868	1.04431	1.05215	1.06217	1.07431	1.08853	1.10476	1.12293	1.14296	1.16476
12.0	1.03710	1.03822	1.04158	1.04716	1.05494	1.06488	1.07694	1.09106	1.10718	1.12523	1.14514	1.16683
12.5	1.04015	1.04126	1.04459	1.05012	1.05784	1.06770	1.07966	1.09368	1.10969	1.12763	1.14741	1.16898
13.0	1.04330	1.04440	1.04770	1.05319	1.06084	1.07062	1.08249	1.09640	1.11230	1.13011	1.14977	1.17121
13.5	1.04656	1.04765	1.05092	1.05636	1.06394	1.07364	1.08542	1.09922	1.11500	1.13269	1.15222	1.17352
14.0	1.04992	1.05100	1.05424	1.05963	1.06715	1.07676	1.08844	1.10213	1.11779	1.13535	1.15475	1.17592
14.5	1.05339	1.05446	1.05767	1.06301	1.07045	1.07998	1.09156	1.10514	1.12067	1.13810	1.15737	1.17840
15.0	1.05695	1.05801	1.06119	1.06648	1.07386	1.08330	1.09477	1.10824	1.12365	1.14095	1.16007	1.18096
15.5	1.06061	1.06166	1.06481	1.07005	1.07735	1.08671	1.09808	1.11143	1.12671	1.14388	1.16286	1.18361
16.0	1.06438	1.06541	1.06853	1.07371	1.08095	1.09021	1.10148	1.11471	1.12986	1.14689	1.16573	1.18633
16.5	1.06823	1.06926	1.07234	1.07747	1.08464	1.09381	1.10497	1.11808	1.13310	1.14999	1.16869	1.18913
17.0	1.07218	1.07320	1.07625	1.08133	1.08842	1.09750	1.10855	1.12154	1.13643	1.15317	1.17172	1.19202
17.5	1.07622	1.07723	1.08025	1.08527	1.09229	1.10128	1.11222	1.12509	1.13984	1.15644	1.17484	1.19498
18.0	1.08035	1.08135	1.08434	1.08930	1.09625	1.10514	1.11598	1.12872	1.14334	1.15979	1.17804	1.19802
18.5	1.08457	1.08556	1.08851	1.09343	1.10029	1.10910	1.11982	1.13244	1.14692	1.16323	1.18132	1.20114
19.0	1.08888	1.08985	1.09277	1.09763	1.10442	1.11314	1.12375	1.13624	1.15058	1.16674	1.18467	1.20433
19.5	1.09327	1.09423	1.09712	1.10193	1.10864	1.11726	1.12776	1.14012	1.15433	1.17033	1.18811	1.20760
20.0	1.09775	1.09870	1.10155	1.10630	1.11294	1.12146	1.13185	1.14409	1.15815	1.17401	1.19162	1.21095
21.0	1.10694	1.10787	1.11066	1.11530	1.12178	1.13012	1.14028	1.15226	1.16604	1.18159	1.19888	1.21787
22.0	1.11645	1.11736	1.12007	1.12460	1.13094	1.13908	1.14902	1.16074	1.17423	1.18947	1.20643	1.22508
23.0	1.12626	1.12714	1.12979	1.13422	1.14040	1.14835	1.15806	1.16953	1.18273	1.19766	1.21428	1.23258
24.0	1.13636	1.13722	1.13981	1.14412	1.15015	1.15792	1.16740	1.17860	1.19152	1.20613	1.22242	1.24037
25.0	1.14673	1.14757	1.15010	1.15430	1.16019	1.16776	1.17702	1.18797	1.20059	1.21489	1.23084	1.24844
26.0	1.15738	1.15820	1.16065	1.16475	1.17049	1.17788	1.18691	1.19760	1.20994	1.22392	1.23954	1.25678
27.0	1.16828	1.16908	1.17147	1.17546	1.18106	1.18826	1.19707	1.20750	1.21956	1.23322	1.24851	1.26539
28.0	1.17942	1.18020	1.18253	1.18642	1.19187	1.19889	1.20749	1.21767	1.22943	1.24279	1.25773	1.27426
29.0	1.19081	1.19156	1.19383	1.19762	1.20293	1.20977	1.21815	1.22808	1.23956	1.25261	1.26722	1.28339
30.0	1.20242	1.20315	1.20536	1.20905	1.21422	1.22088	1.22905	1.23873	1.24994	1.26267	1.27695	1.29276

o horizontal span length

span (percent)

60	65	70	75	80	85	90	95	100	105	110	115	120
1.16636	1.19284	1.22080	1.25014	1.28075	1.31256	1.34547	1.37941	1.41431	1.45009	1.48669	1.52405	1.56212
1.16657	1.19304	1.22099	1.25031	1.28091	1.31271	1.34561	1.37954	1.41443	1.45020	1.48679	1.52414	1.56221
1.16686	1.19331	1.22124	1.25055	1.28113	1.31291	1.34580	1.37972	1.41459	1.45035	1.48693	1.52428	1.56233
1.16724	1.19367	1.22157	1.25085	1.28142	1.31318	1.34605	1.37995	1.41480	1.45055	1.48711	1.52445	1.56249
1.16770	1.19410	1.22197	1.25123	1.28177	1.31350	1.34635	1.38023	1.41506	1.45079	1.48734	1.52465	1.56268
1.16825	1.19461	1.22245	1.25167	1.28218	1.31389	1.34670	1.38056	1.41537	1.45107	1.48760	1.52490	1.56291
1.16888	1.19520	1.22300	1.25218	1.28266	1.31433	1.34712	1.38094	1.41572	1.45140	1.48791	1.52518	1.56317
1.16959	1.19587	1.22362	1.25276	1.28320	1.31483	1.34758	1.38137	1.41612	1.45177	1.48825	1.52550	1.56347
1.17039	1.19661	1.22432	1.25341	1.28380	1.31539	1.34810	1.38185	1.41657	1.45219	1.48864	1.52586	1.56380
1.17127	1.19744	1.22509	1.25413	1.28447	1.31601	1.34868	1.38239	1.41707	1.45265	1.48907	1.52626	1.56417
1.17223	1.19834	1.22593	1.25491	1.28520	1.31669	1.34931	1.38297	1.41761	1.45315	1.48953	1.52669	1.56457
1.17328	1.19932	1.22684	1.25577	1.28599	1.31743	1.34999	1.38361	1.41820	1.45370	1.49004	1.52717	1.56501
1.17441	1.20037	1.22783	1.25669	1.28685	1.31822	1.35073	1.38430	1.41884	1.45430	1.49059	1.52768	1.56549
1.17562	1.20151	1.22889	1.25768	1.28777	1.31908	1.35153	1.38504	1.41953	1.45493	1.49119	1.52823	1.56600
1.17691	1.20272	1.23003	1.25873	1.28875	1.32000	1.35238	1.38583	1.42026	1.45561	1.49182	1.52881	1.56654
1.17829	1.20401	1.23123	1.25986	1.28980	1.32097	1.35329	1.38667	1.42104	1.45634	1.49249	1.52944	1.56713
1.17975	1.20538	1.23251	1.26105	1.29091	1.32201	1.35425	1.38756	1.42187	1.45711	1.49321	1.53010	1.56774
1.18129	1.20682	1.23386	1.26231	1.29209	1.32310	1.35527	1.38851	1.42275	1.45793	1.49397	1.53081	1.56840
1.18291	1.20834	1.23528	1.26364	1.29333	1.32425	1.35634	1.38951	1.42368	1.45879	1.49476	1.53155	1.56909
1.18461	1.20994	1.23678	1.26504	1.29463	1.32547	1.35747	1.39055	1.42465	1.45969	1.49560	1.53233	1.56981
1.18640	1.21161	1.23835	1.26650	1.29599	1.32674	1.35865	1.39166	1.42568	1.46064	1.49649	1.53315	1.57057
1.18826	1.21336	1.23998	1.26803	1.29742	1.32807	1.35989	1.39281	1.42675	1.46164	1.49741	1.53401	1.57137
1.19021	1.21519	1.24170	1.26963	1.29892	1.32946	1.36118	1.39401	1.42787	1.46268	1.49838	1.53491	1.57221
1.19223	1.21709	1.24348	1.27130	1.30047	1.33091	1.36254	1.39527	1.42903	1.46376	1.49939	1.53585	1.57308
1.19434	1.21907	1.24533	1.27304	1.30209	1.33242	1.36394	1.39658	1.43025	1.46489	1.50044	1.53682	1.57399
1.19652	1.22113	1.24726	1.27484	1.30378	1.33399	1.36540	1.39794	1.43152	1.46607	1.50153	1.53784	1.57493
1.19878	1.22325	1.24926	1.27671	1.30552	1.33562	1.36692	1.39935	1.43283	1.46729	1.50267	1.53890	1.57592
1.20112	1.22546	1.25132	1.27864	1.30733	1.33731	1.36850	1.40082	1.43420	1.46856	1.50385	1.53999	1.57693
1.20354	1.22774	1.25346	1.28065	1.30921	1.33906	1.37013	1.40234	1.43561	1.46988	1.50507	1.54113	1.57799
1.20604	1.23009	1.25567	1.28272	1.31114	1.34087	1.37181	1.40391	1.43707	1.47124	1.50634	1.54231	1.57909
1.20861	1.23251	1.25795	1.28486	1.31314	1.34274	1.37356	1.40553	1.43858	1.47264	1.50765	1.54352	1.58022
1.21127	1.23501	1.26030	1.28706	1.31521	1.34466	1.37536	1.40721	1.44015	1.47410	1.50900	1.54478	1.58139
1.21399	1.23759	1.26273	1.28933	1.31733	1.34665	1.37721	1.40894	1.44176	1.47560	1.51039	1.54608	1.58260
1.21680	1.24023	1.26522	1.29167	1.31952	1.34870	1.37912	1.41072	1.44342	1.47715	1.51183	1.54742	1.58384
1.21968	1.24295	1.26778	1.29408	1.32178	1.35081	1.38109	1.41256	1.44513	1.47874	1.51332	1.54880	1.58513
1.22263	1.24575	1.27041	1.29655	1.32409	1.35298	1.38312	1.41445	1.44689	1.48038	1.51485	1.55022	1.58645
1.22566	1.24861	1.27311	1.29908	1.32647	1.35520	1.38520	1.41639	1.44870	1.48207	1.51642	1.55169	1.58782
1.22877	1.25154	1.27587	1.30169	1.32892	1.35749	1.38734	1.41839	1.45057	1.48380	1.51804	1.55319	1.58922
1.23194	1.25455	1.27871	1.30436	1.33142	1.35984	1.38953	1.42044	1.45248	1.48559	1.51970	1.55474	1.59066
1.23852	1.26078	1.28459	1.30989	1.33662	1.36471	1.39410	1.42470	1.45646	1.48930	1.52316	1.55796	1.59366
1.24538	1.26728	1.29074	1.31569	1.34207	1.36983	1.39889	1.42918	1.46064	1.49320	1.52679	1.56135	1.59682
1.25253	1.27406	1.29715	1.32174	1.34777	1.37518	1.40390	1.43387	1.46503	1.49730	1.53062	1.56492	1.60014
1.25995	1.28112	1.30384	1.32805	1.35372	1.38077	1.40915	1.43879	1.46962	1.50159	1.53462	1.56865	1.60362
1.26765	1.28845	1.31078	1.33462	1.35991	1.38660	1.41462	1.44392	1.47442	1.50608	1.53881	1.57256	1.60727
1.27562	1.29604	1.31799	1.34145	1.36635	1.39267	1.42032	1.44927	1.47943	1.51076	1.54319	1.57665	1.61109
1.28386	1.30389	1.32546	1.34852	1.37304	1.39897	1.42625	1.45483	1.48465	1.51565	1.54776	1.58092	1.61507
1.29235	1.31200	1.33318	1.35584	1.37997	1.40551	1.43241	1.46062	1.49008	1.52073	1.55251	1.58536	1.61922
1.30111	1.32037	1.34115	1.36342	1.38714	1.41228	1.43879	1.46662	1.49572	1.52602	1.55746	1.58999	1.62354
1.31011	1.32898	1.34937	1.37123	1.39455	1.41929	1.44541	1.47285	1.50157	1.53150	1.56260	1.59480	1.62804

Unit No. _____

Skyline Road No. _____

DETERMINE FROM SKYLINE PROFILE:

Allowable loaded deflection _____ percent

Horizontal span length (one station = 100 feet) _____ stations

Slope of span _____ percent

GIVEN:

Cable: Diameter _____ inches   Weight _____ pounds/foot

Breaking strength _____ kips (1 kip = 1,000 pounds)

Factor of safety _____   Safe working load _____ kips

Skyline carriage weight _____ kips

DETERMINE REMAINING CABLE TENSION CAPABILITY:

Safe working load (given) _____ kips

Subtract tension due to cable weight (fig. 11 or table 2):

_____ kips/sta./lb./ft. x _____ stations x _____ lbs./ft. - _____ kips

Remaining cable tension capability _____ kips

DETERMINE GROSS LOAD CAPABILITY:

$$\frac{\text{Remaining tension capability \_\_\_\_\_ kips}}{\text{Tension/kip of load* \_\_\_\_\_ kips/kip}}$$ _____ kips

Subtract carriage weight - _____ kips

Payload capability _____ kips

DETERMINE UNLOADED DEFLECTION:

Calculate load factor:

$$\frac{\text{Remaining cable tension capability \_\_\_\_\_ kips}}{\text{Tension due to cable weight \_\_\_\_\_ kips/sta./lb./ft. x \_\_\_\_\_ lb./ft.}}$$ _____

Allowable loaded deflection _____ percent

Subtract deflection change with load removed (figs. 14 to 29) - _____ percent

Unloaded deflection _____ percent

DETERMINE UNLOADED TENSION USING UNLOADED DEFLECTION (fig. 11 or table 2):

_____ kips/sta./lb./ft. x _____ stations x _____ pounds/foot _____ kips

*Use figure 12 or table 3 when load is not clamped and is partially supported by a snubbing line. Use figure 13 or table 4 when the load is clamped to the skyline.

Figure 30.--Single-span skyline worksheet.

Unit No. _____

Skyline Road No. _____

DETERMINE FROM SKYLINE PROFILE:

Span location — Span No. _____

Loaded-midspan deflection _____ percent

Horizontal span length (one station = 100 feet) _____ stations

Slope of span _____ percent

Vertical distance from top of span to top of skyline _____ feet

GIVEN:

Cable: Diameter _____ inches Weight _____ pounds/foot

Breaking strength _____ kips (1 kip = 1,000 pounds)

Factor of safety _____ Safe working load _____ kips

Skyline carriage weight _____ kips

DETERMINE REMAINING CABLE TENSION CAPABILITY:

Safe working load (given) _____ kips

Subtract tension between span and top of skyline:

Vertical distance _____ ft. x _____ lbs./ft./1,000 - _____ kips

Safe working load at top of span _____ kips

Subtract tension due to cable weight (fig. 11 or table 2):

_____ kips/sta./lb./ft. x _____ stations x _____ lb./ft. - _____ kips

Remaining cable tension capability _____ kips

DETERMINE GROSS LOAD CAPABILITY:

$\dfrac{\text{Remaining tension capability \_\_\_\_\_ kips}}{\text{Tension/kip of load* \_\_\_\_\_ kips/kip}}$ _____ kips

Subtract carriage weight - _____ kips

Payload capability of span _____ kips

*Use figure 12 or table 3 when load is not clamped and is partially supported by snubbing line. Use figure 13 or table 4 when load is clamped to skyline.

Figure 31.--Multispan skyline worksheet.

Lysons, Hilton H., and Mann, Charles N.
1967. Skyline tension and deflection handbook. U.S. Forest Serv. Res. Pap. PNW-39, 41 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Gives procedures for calculating the tensions, deflections and lengths of single and multispan skylines as required for their efficient use. It is an expansion of the "Skyline Logging Handbook on Wire Rope Tensions and Deflections," published in 1965.

Lysons, Hilton H., and Mann, Charles N.
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Lysons, Hilton H., and Mann, Charles N.
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